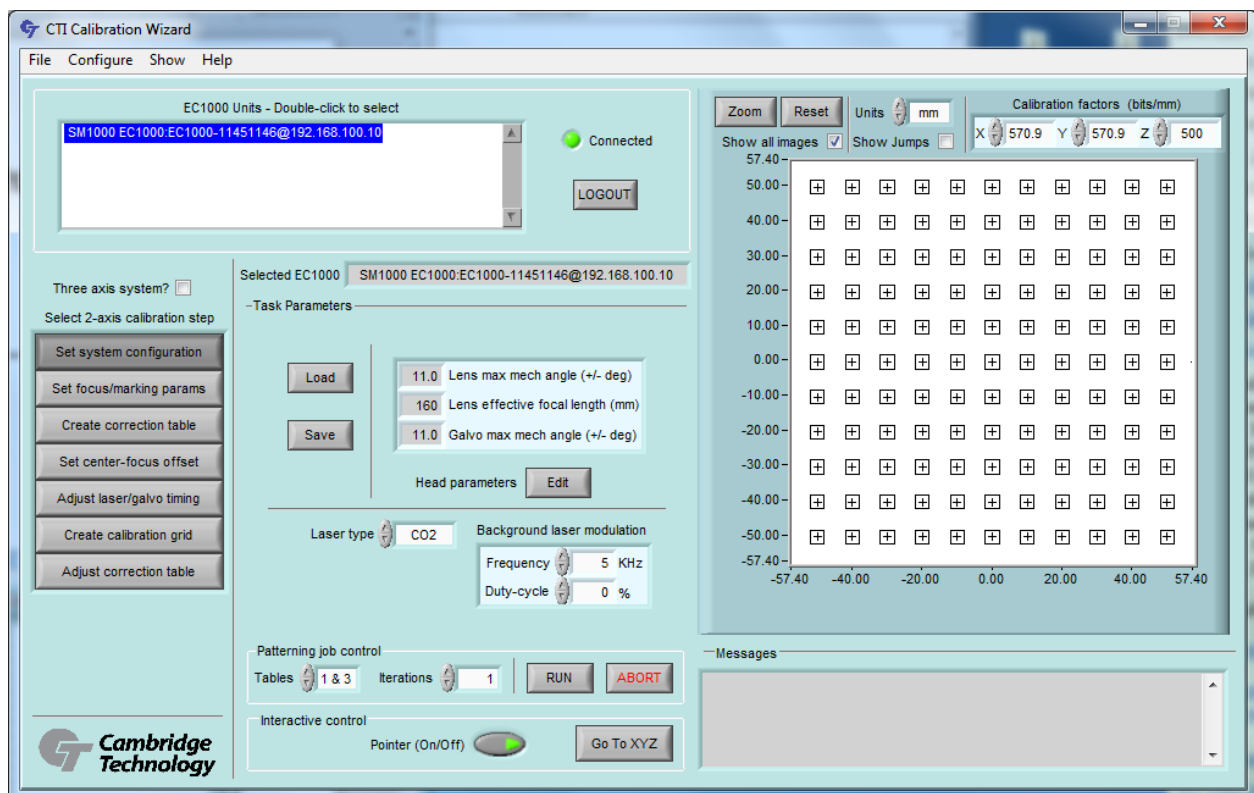
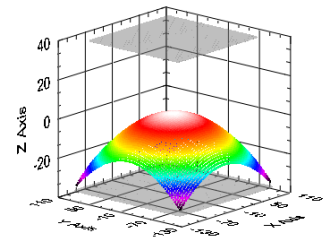




User Manual

Calibration Wizard





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Table 1 Revision history

Rev	Date	Changes
A	2/14/2012	First general release
B	10/16/2012	Update for V1.2 Changes; Add more information on the calibration process.
C	09/26/2013	Update for V1.3 Changes; Separate 2-Axis and 3-Axis procedures.
D	04/03/2014	Update for V1.5 changes; New presentation.
D	05/12/2014	Added figure captions to all figures. Made extensive copy-edits and technical updates.

Introduction

A correction table is used by a scan controller to compensate for projection distortions due to physical geometry of the steering system, non-ideal opto-mechanical fabrication tolerances, electrical non-linearity of the galvanometer position control system, lens radial distortion, system misalignment and scaling errors.

The process of creating a correction table is iterative, as depicted in Figure 1 below.

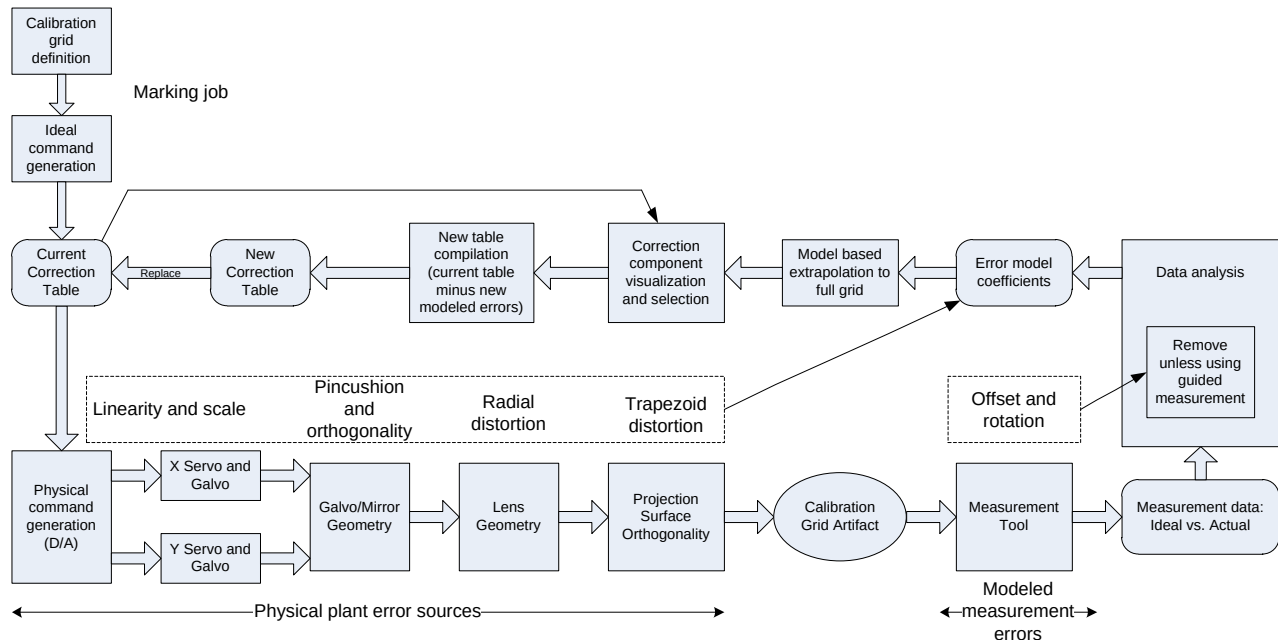


Figure 1: Overall View of the Calibration Process

While it is possible to create a correction table starting without any correction, it is recommended to start the process by applying a synthesized correction – a correction calculated based on the system's geometry.

For a 3D correction table, the above process is used to define the X & Y corrections, while the initial calculated Z correction is adjusted by “Flattening the Field” – ensuring consistent focus over the entire scan field.

The Calibration Wizard supports the following methods to acquire the measured coordinates:

- Automatic analysis of a scanned grid image from a flat-bed scanner
- Analysis of a grid measurement file provided by the user
- Manual guided grid adjustments
- Basic Box corrections

Each of the above methods differs in required effort and achievable accuracy. Refer to “Calibration Methods” on page 61 to select the method that best suits your needs.

Interface Identification

Interaction with the Calibration Wizard is done through the Main Window and the Correction Table Editor.

Main Window

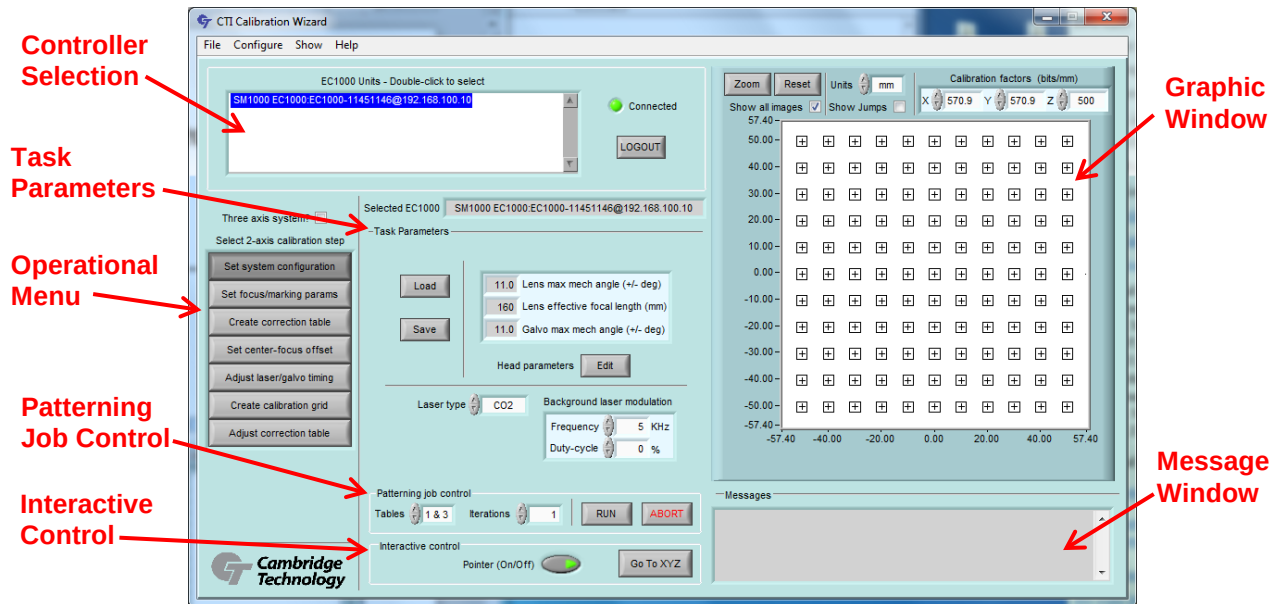


Figure 2: Calibration Wizard main interface

The use of the Controller Selection, Operational Menu, Tasks Parameters and Graphic Window is described later in the manual. The use of Patterning Job Control, Interactive Control, and the Message Window is as follows:

- Patterning Job Control – used to select the following:
 - Tables
 - 1 & 3 – Correction tables for Main Laser 1 and Main Laser 2 respectively.
 - 2 & 4 – Correction tables for Guide Laser 1 and Guide Laser 2 respectively.
 - Iterations – How many times the job will be executed
 - Run – Instructs the connected controller to execute the current job
 - Abort – Instructs the connected controller to abort execution of the current job
- Interactive control window – used to do the following:
 - Pointer (On/Off) – Activates / deactivates the guide laser.
 - Go To XYZ – Moves the galvos to point at the required XYZ coordinate within the scanner's field.
- Messages Window – used to display event information, error messages and other information generated during the controller's operation.

Correction Table Editor

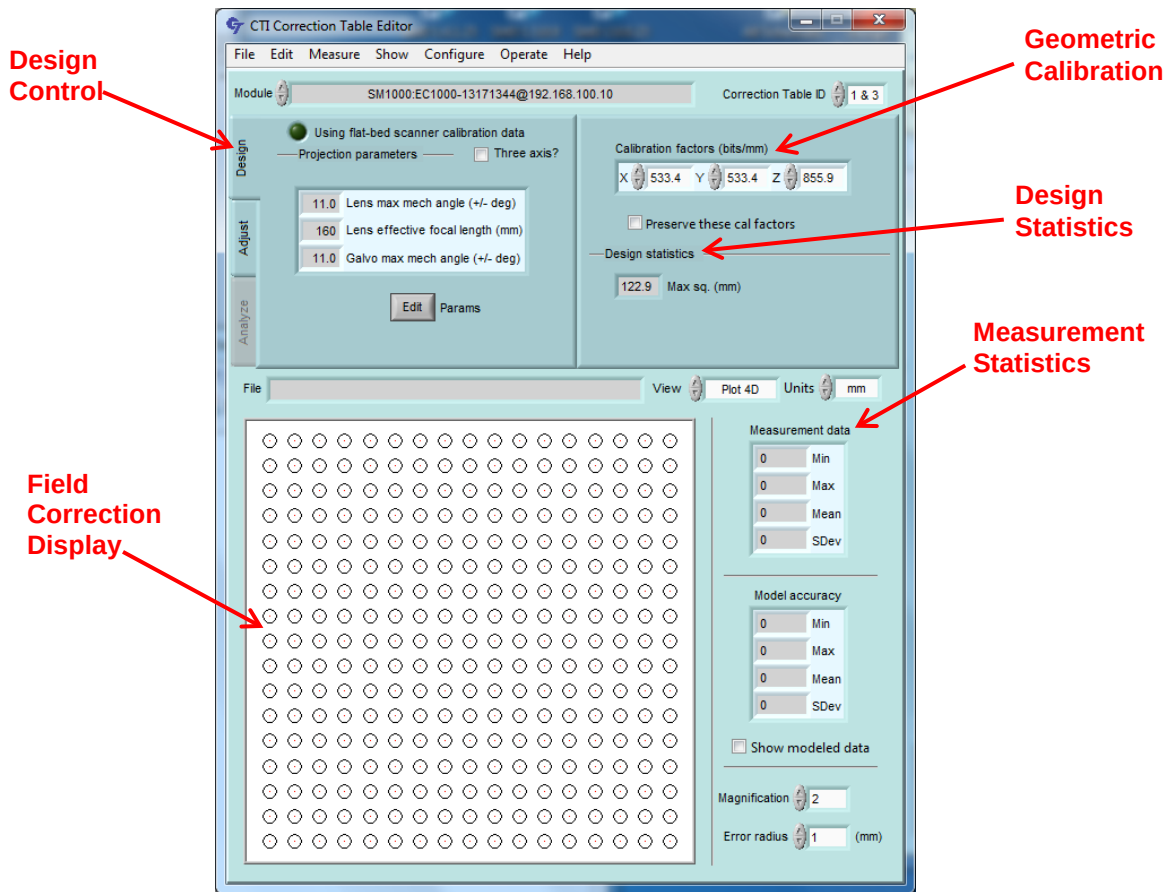


Figure 3: Correction Table Editor

The use of these controls is described later in the manual.

Principles of Operation

Correction Table Structure

The correction table has 4225 entries for each of the three axes (X, Y and Z). The table is arranged in a 65x65 matrix corresponding to command values ranging from (-32768, -32768) to (32767, 32767) in X-Y Cartesian coordinates. The coordinates of the table are spaced apart at 1024 counts in both X and Y. An X, Y, and Z correction value is defined at each coordinate of the table.

Table entries are offsets that are added to the command value to create a new “corrected” value that causes the beam to deflect in such a way as to compensate for distortions induced by the lens, mirror spacing, and system alignment errors. Job command values that fall between the defined coordinates of the table are compensated by using a bi-linear interpolation of the four immediately adjacent defined table coordinates.

The number of measured points is often very low compared to the size of the table, so mathematical error sources models (based on bi-linear interpolation) are used to populate table entries where measurements are not directly available. This is possible as the errors encountered in such a steering system are smoothly varying functions.

Measurement results are folded back into the table to create more optimized values. The final accuracy of the steering system is a direct function of the number of points that are measured, and how accurate the measurements are.

Correction Table Utilization

The controller can use up to four different correction tables in pairs of two. There are two tables in use at all times. Tables 1 & 2 are used with the analog outputs and the XY2-100e output, while tables 3 & 4 are used with the standard XY2-100 output.

Typically, tables 1 & 3 are used to correct for distortions when using the marking laser, while Tables 2 & 4 are used when a pointer laser is active. In cases where the controller is driving two scan-heads, it is possible to specify data for tables 3 & 4 independent of the data in tables 1 & 2.

Using the Calibration Wizard

The Calibration Wizard can be used for three different activities:

1. Creation of a new correction table
2. Full adjustment of an existing correction table using a grid
3. Global adjustment of an existing correction table using a simple Box & Cross pattern

The following pages provide a brief overview of the creation of a new correction table.

A separate overview is provided for 2-Axis configurations and for 3-Axis ones, as a 3-Axis configuration requires a few additional steps.

This “high-level” overview is useful for understanding the full process, and it also serves as a “check list” for experienced users.

The chapters that follow describe each of the process steps in detail.

If you use the manual on a computer, use the links to jump from the overview into the detailed section of each step, and then back to the overview.

If you prefer a printed version, identify the sections that are relevant for your situation and rearrange the printed pages to create your own manual.

To create a new correction table

Follow the full process without skipping a step.

To adjust a previously saved correction table

To perform a complete adjustment of the correction table, skip to the “Create correction table” step of the relevant overview in the following pages. Click on the “Edit table” button to invoke the CTI Correction Table Editor window.

1. To perform a simple adjustment of the correction table, skip to the “Adjust correction table” step of the relevant overview in the following pages. Click on the “Edit corr table” button to invoke the CTI Correction Table Editor window.

2. Use the **File | Load | Correction table... | From local file** menu option to load the file you have saved before.

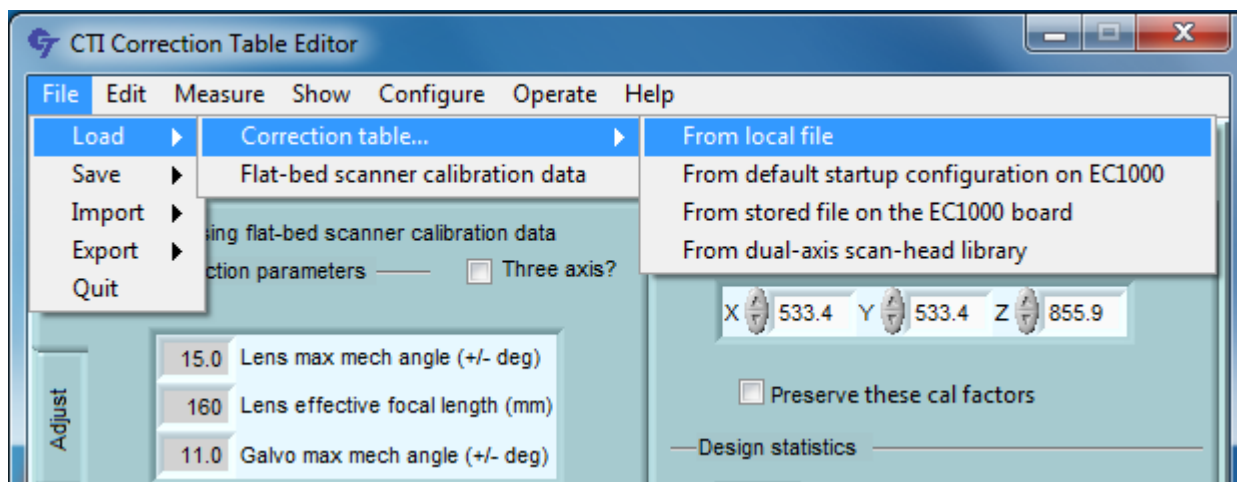


Figure 4: Load Correction Table Menu Option

3. A browser window will open to enable you to find and select the file you want to load:

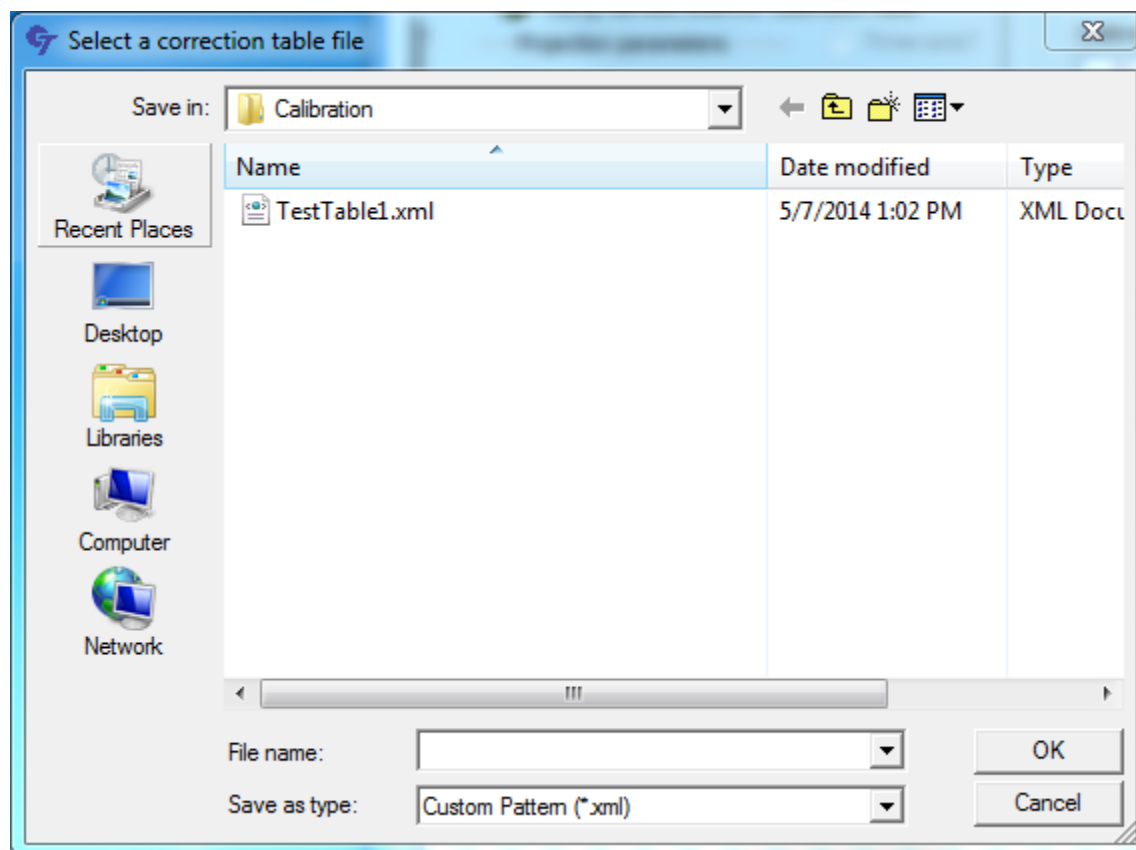
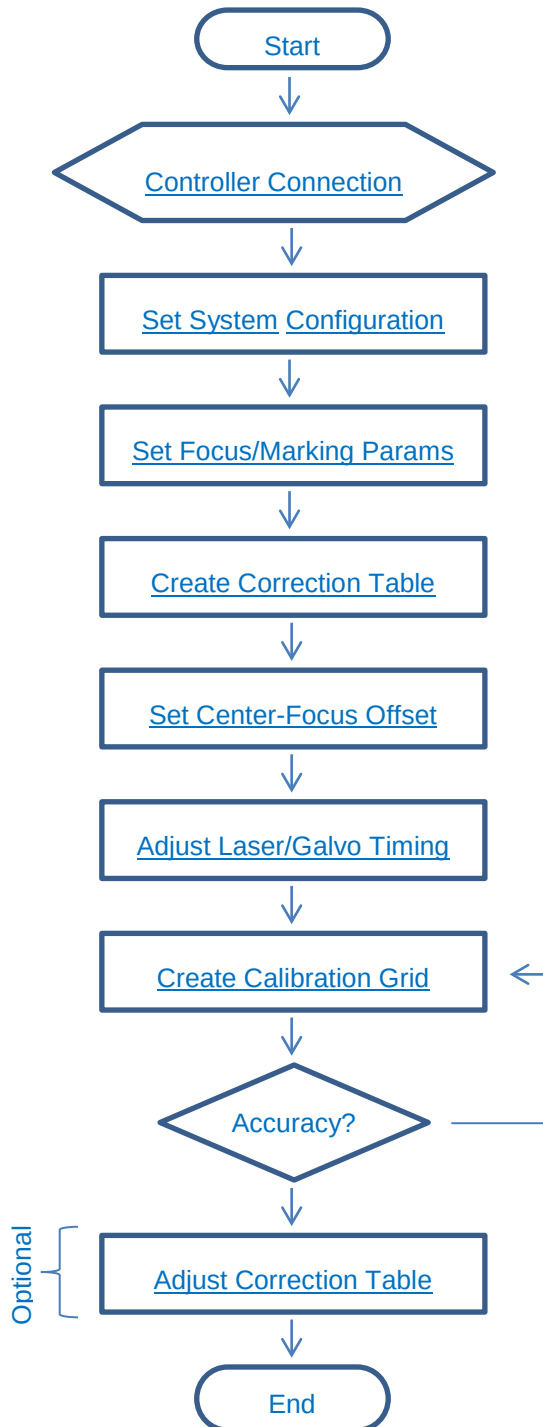


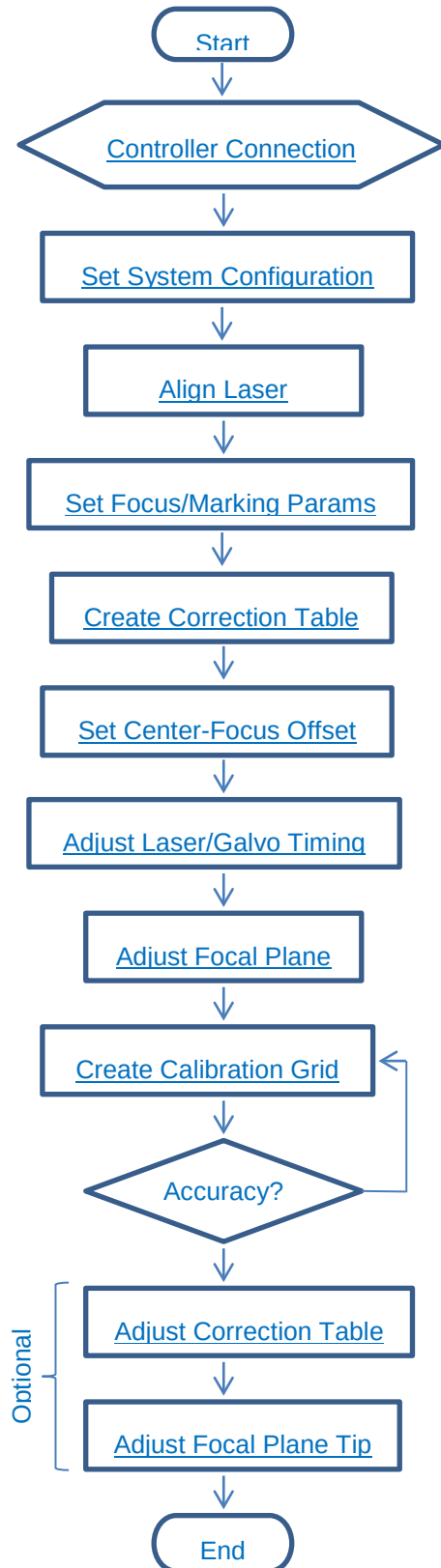
Figure 5: Select Correction Table Window

2-Axis Head Procedure Overview



- Activate the Calibration Wizard.
- Connect to an EC1000 or SM1000 controller.
- Enter the lens's maximum mechanical angle & effective focal length and the galvo's maximum mechanical angle.
- Set the laser information along with the background modulation frequency and duty cycle.
- Set Mark and Jump speeds for focus test, general marking and cutting.
- Set laser frequency, duty cycle, and power levels for the above.
- Load a Correction Table if available.
- Exit the correction table editor by selecting File and Quit.
- **Accept the table when prompted.**
- Mark the grid at the center of the field.
- Identify the offset step that achieves best focus and set it in the Correction Table Editor (launched with the "Edit Table" button).
- Set optimum laser and scanner delays, as well as Velocity compensation if used.
- At this point you may want to **save the setup parameters** (file\Save calibration configuration).
- Define the grid's type, sizes and spacing.
- Mark the grid
- Measure grid coordinates.
- Analyze the measurement results.
- Close the correction table editor and select yes to **apply the new corrections**.
- Repeat the marking & analysis process until the required accuracy is achieved.
- **Save the correction data to an xml file.**

3-Axis Head Procedure Overview



- Activate the Calibration Wizard.
- Connect to an EC1000 or SM1000 controller.
- Check the "Three axis system?" checkbox.
- Select head type from list or create a custom one by entering the head's parameters as required.
- Set laser information along with the background modulation frequency and duty cycle
- Set relevant laser parameters for alignment (can vary based on laser type selection).
- Use the manual "Activate laser" control to align (or verify the alignment of) the laser beam with the optical axis of the head.
- Set Mark and Jump speeds for focus test, general marking and cutting.
- Set laser frequency, duty cycle, and power levels for the above.
- Load a Correction Table if available.
- Exit the correction table editor by selecting File and Quit.
- **Accept the table when prompted.**
- Mark the grid at the center of the field.
- Identify the offset step that achieves best focus and set it in the Correction Table Editor (launched with the "Edit Table" button).
- Set optimum laser and scanner delays, as well as Velocity compensation if used.
- At this point you may want to **save the setup parameters** (file\Save calibration configuration).
- Mark the pattern and adjust the Z Calibration factor until focus is achieved near the center of all marked grids.
- Define the grid's type, sizes and spacing.
- Mark the grid.
- Measure grid coordinates.
- Analyze the measurement results.
 - Close the correction table editor and select yes to **apply the new corrections.**
- Repeat the marking & analysis process until the required accuracy is achieved.
- **Save the correction data to an xml file.**
- If global field adjustment is needed, mark the grid. Then go to the correction table editor and select **Measure → Collect Box/Cross** grid data to adjust the table for overall scaling and trapezoid distortion.
- If required, mark the pattern. Then go to the correction table editor and select **Measure → Collect** focal plane data to adjust the focal plane's tip until focus is achieved at the center of all marked grids.

Process Steps

Controller Connection

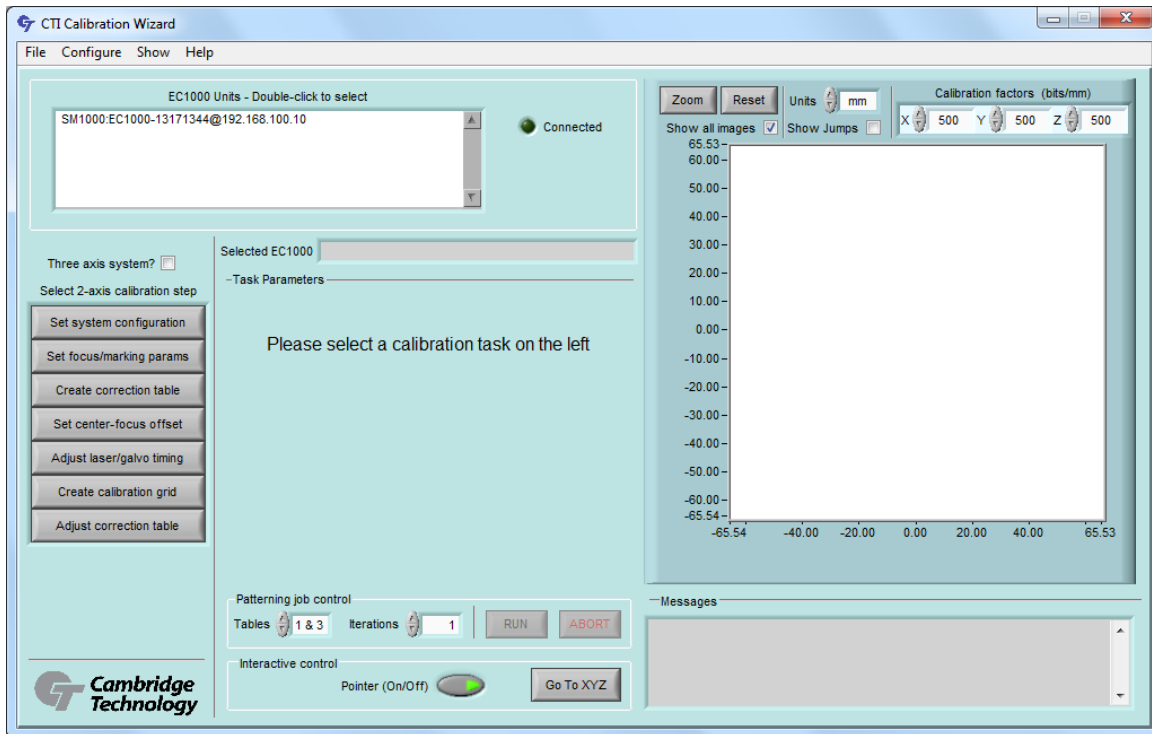


Figure 6: Calibration Wizard Main Window

1. Upon activation, if your computer has more than one network adaptor, you will be asked to select the one that is used for scan control by double-clicking it.

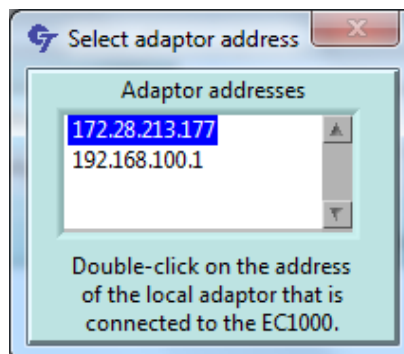


Figure 7: Select Adaptor Address

- The Calibration Wizard application will search for available controllers and display them in the Controller Selection window.



Figure 8: Controller Selection Window

- Double-click on the controller you wish to connect to.
- Status windows will appear for a few seconds.

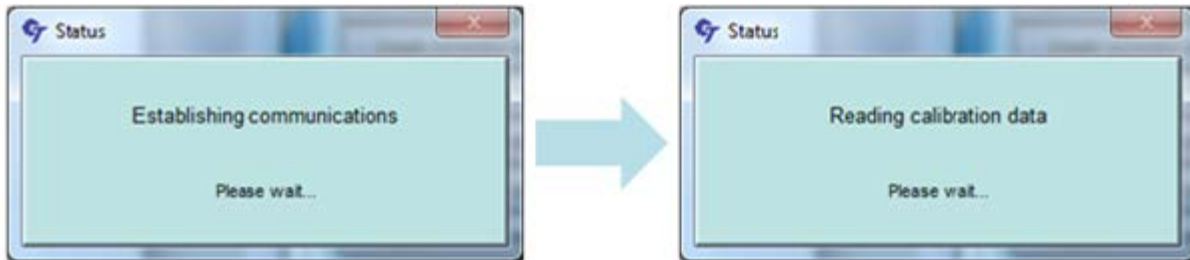


Figure 9: Controller Connection Status Windows

- And finally, the “Connected” indicator will turn green.

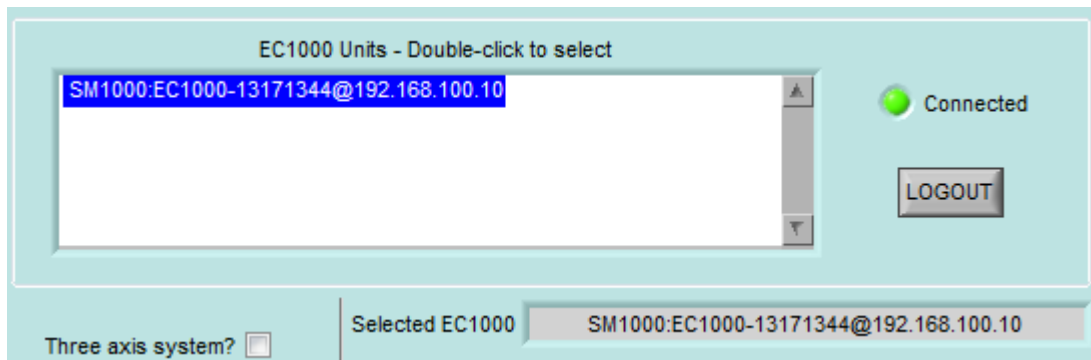


Figure 10: Connected Indicator

Note: If the controller has a correction table present, it will be loaded and the selection of 2-Axis vs. 3-Axis will be done automatically to reflect the information in this table.

To return to the procedure overview for 2-axis heads, click on [2-Axis Head Procedure Overview](#).

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Set System Configuration – 2-Axis Heads

If you have saved a calibration configuration in the past, you can load it from the File menu.

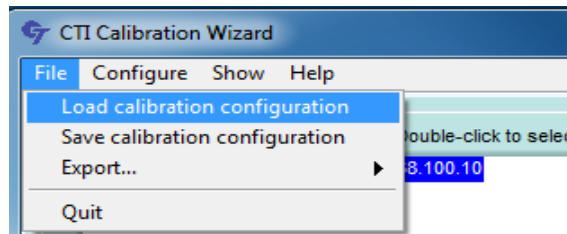


Figure 11: File | Load calibration configuration

1. The software will recognize the configuration and will automatically set all the fields.
2. If you do not have a previously saved configuration, start by selecting the type of system you have (2-Axis) to display the relevant menu. The first button is the **Set system configuration** button:

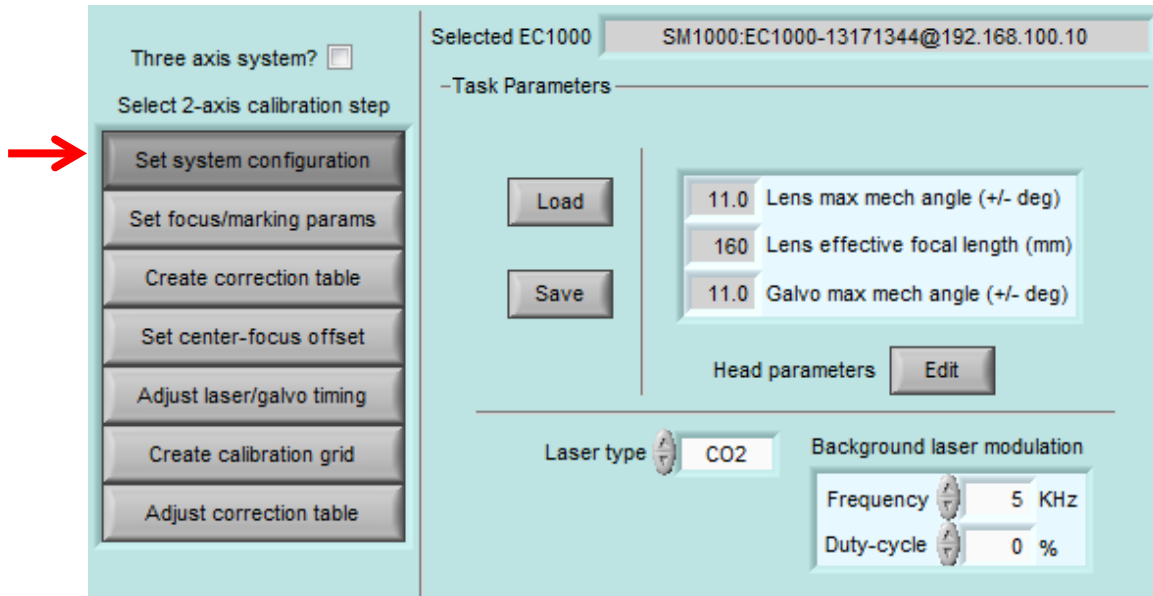


Figure 12: System Type Selection & Menu (2-Axis configuration)

3. In the **Task parameters** window you can select or set the following head-related parameters for synthesizing a correction table:
 - Lens max mech angle ($\pm$ deg)
 - Lens effective focal length (mm)
 - Galvo max mech angle ($\pm$ deg)

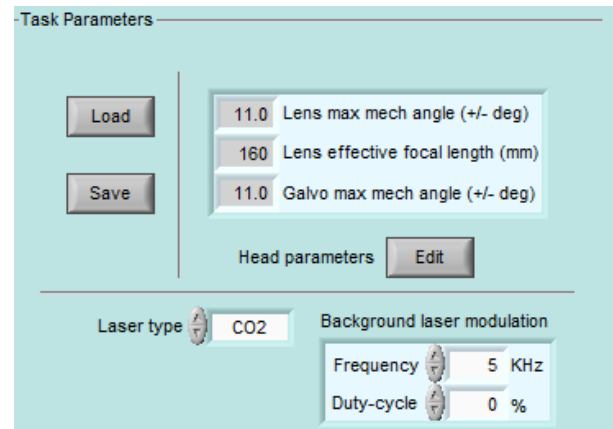


Figure 13: Task Parameters (2-Axis configuration)

4. In addition, the following laser-related parameters can be set to inform the software what laser controls to display in subsequent screens, and how to manage the laser when it is NOT lasing:

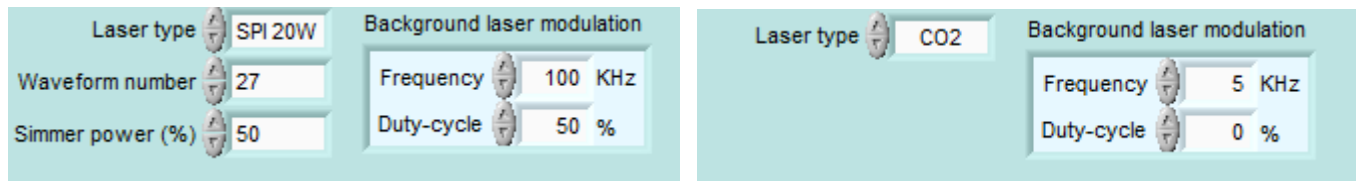


Figure 14: Laser Settings

- Laser type: CO₂, IPG YLP, IPG YLS, IPG YLR, SPI 12W, SPI 20W, Generic
 - Waveform number: *For SPI laser types only*
 - Simmer power (%): *For SPI laser types only*
 - Frequency (kHz): *For Background modulation (when laser is “off”)*
 - Duty-cycle (%): *For Background modulation (when laser is “off”)*
5. At this time, it is recommended that you verify/adjust your laser properties through the **Configure | Laser Properties** menu option:

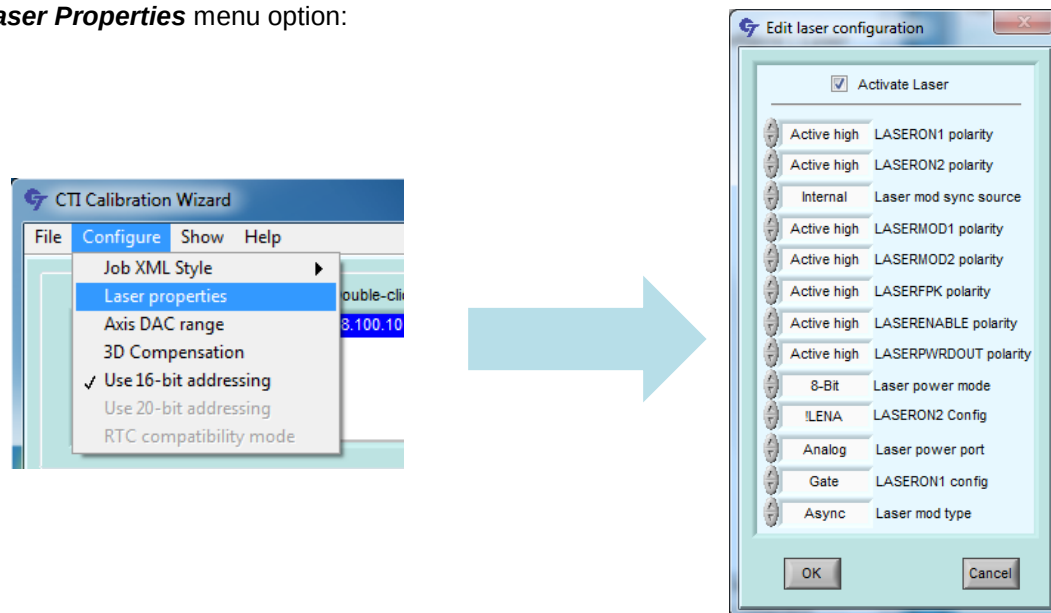


Figure 15: Laser Properties

6. Finally, save the configuration for future reference through the File menu.

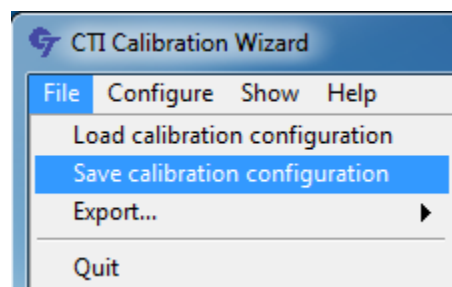


Figure 16: File | Save calibration configuration

To return to the procedure overview for 2-axis heads, click on [2-Axis Head Procedure Overview](#).

Set System Configuration – 3-Axis Heads

If you have saved a calibration configuration in the past, you can load it from the File menu.

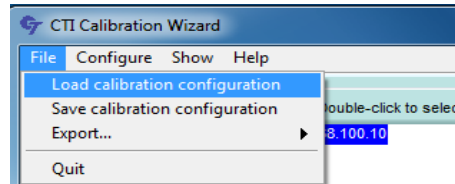


Figure 17: File | Load calibration configuration

1. The software will recognize the configuration and will automatically set all the fields.
2. If you do not have a previously saved configuration, start by selecting the type of system you have (3-Axis) to display the relevant menu. The first button is the **Set system configuration** button:

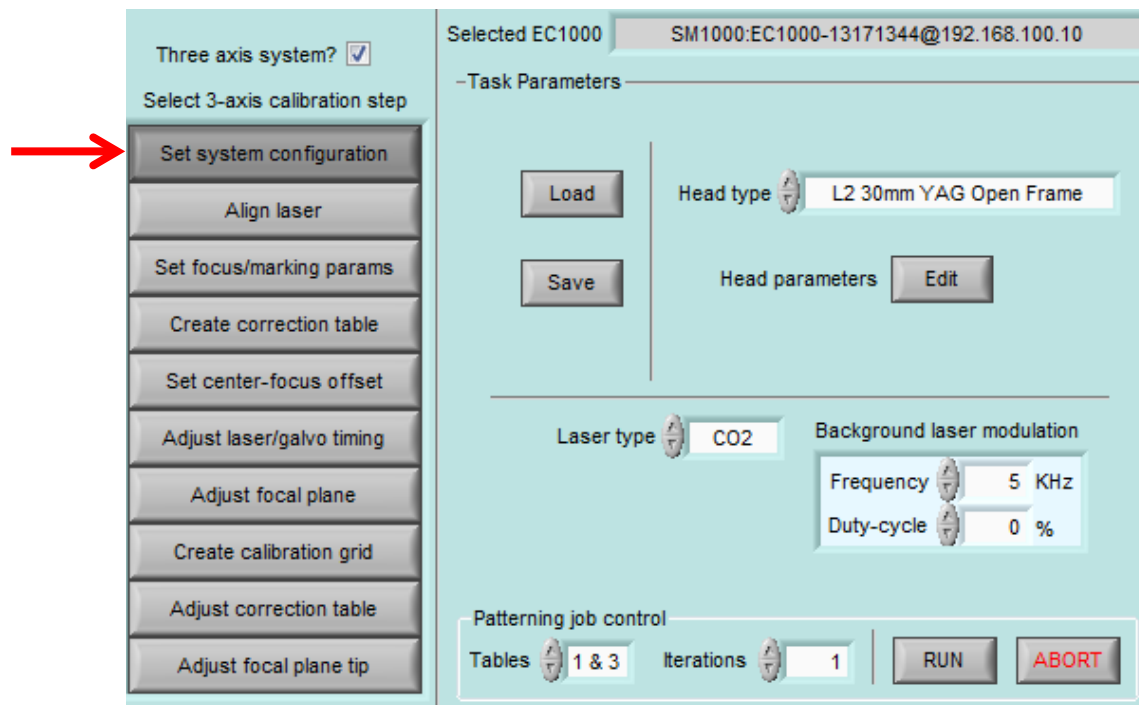


Figure 18: System Type Selection & Menu (3-Axis configuration)

3. In the **Task parameters** window you can select or set head-related parameters to be used for synthesizing a correction table. For 3-Axis heads, preset parameters are selected by selecting from the supported head type list.

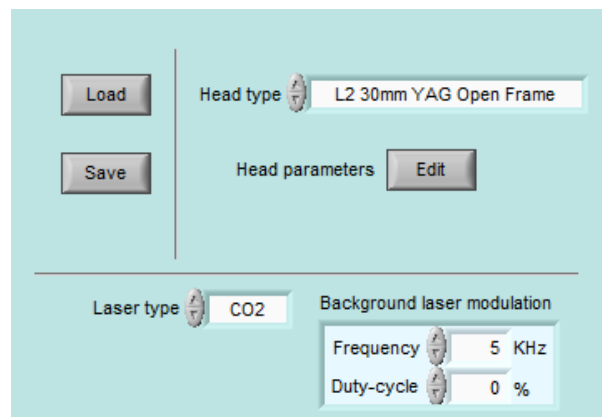


Figure 19: Task Parameters (3-Axis configuration)

4. If a custom head configuration is used, click the Edit button to enter the following head parameters:

- X mirror to objective distance (mm)
- X to Y mirror distance (mm)
- Y mirror to work surface distance (mm)
- X Galvo mech half-angle (deg)
- Y Galvo mech half-angle (deg)

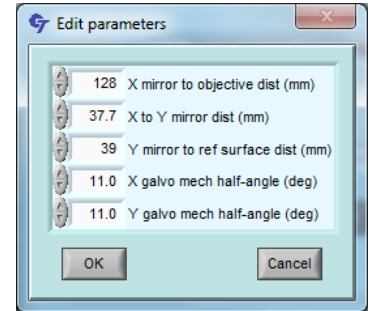


Figure 20: Head Parameters

5. In addition, the following laser-related parameters can be set to inform the software what laser controls to display in subsequent screens, and how to manage the laser when it is NOT lasing:



Figure 21: Laser Settings

- Laser type: CO₂, IPG YLP, IPG YLS, IPG YLR, SPI 12W, SPI 20W, Generic
 - Waveform number: *For SPI laser types only*
 - Simmer power (%): *For SPI laser types only*
 - Frequency (kHz): *For Background modulation (when laser is "off")*
 - Duty-cycle (%): *For Background modulation (when laser is "off")*
6. At this time, it is recommended that you verify/adjust your laser properties through the **Configure | Laser Properties** menu option:

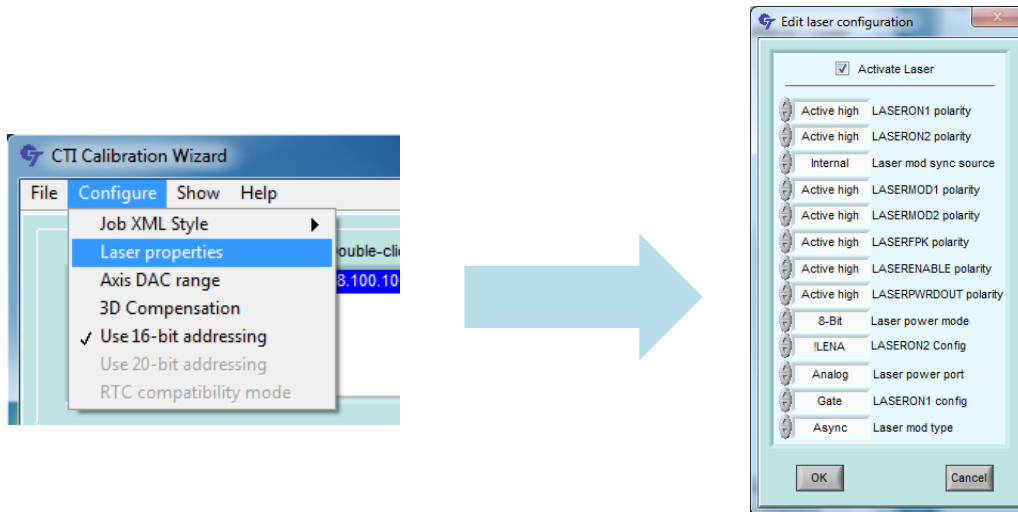


Figure 22: Laser Properties

- Finally, save the configuration for future reference through the File menu.

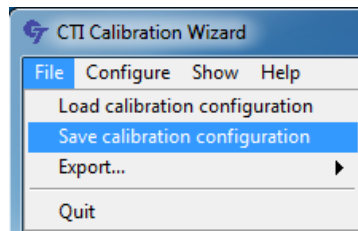


Figure 23: File | Save calibration configuration

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Align Laser – 3-Axis Heads

2-Axis heads are mechanically aligned to the laser by the way they are attached. 3-Axis systems, on the other hand, require alignment of the laser beam to the optical path of the head. To enable the alignment process, manual laser control is available by clicking the **Align laser** button.

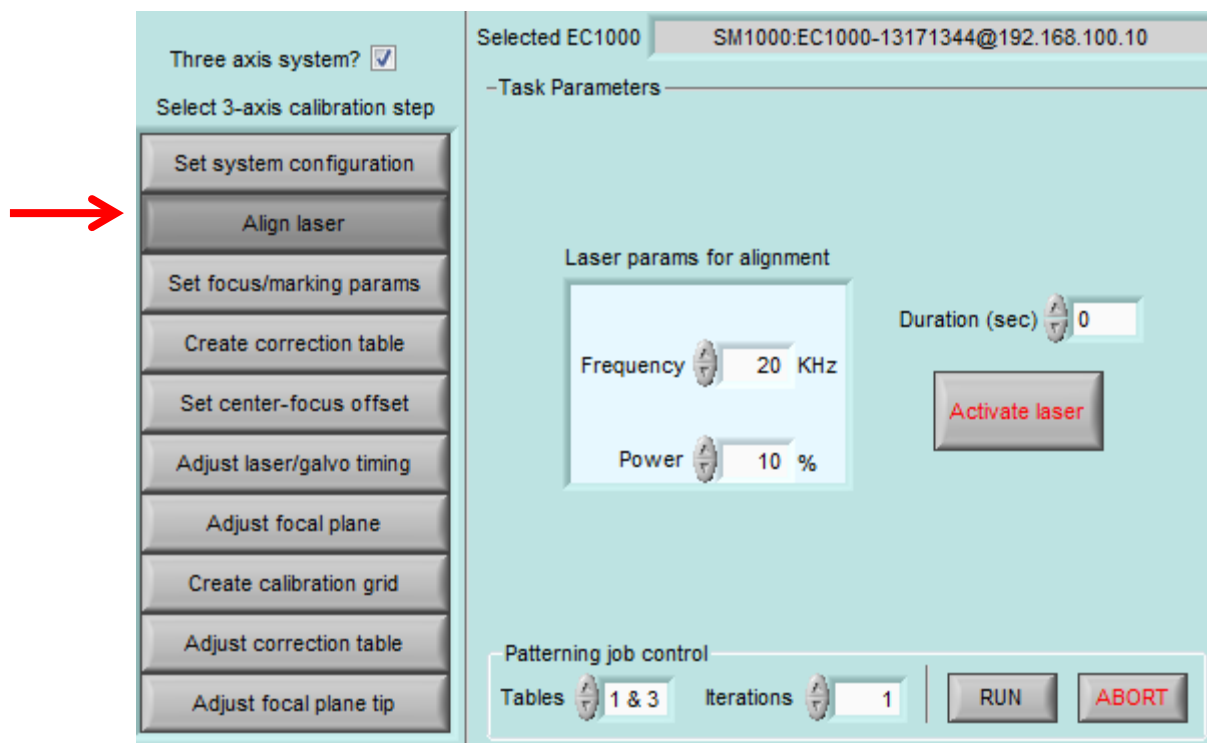


Figure 24: Laser Align View

1. The available **Laser params** dependent on the laser selection in the previous step:

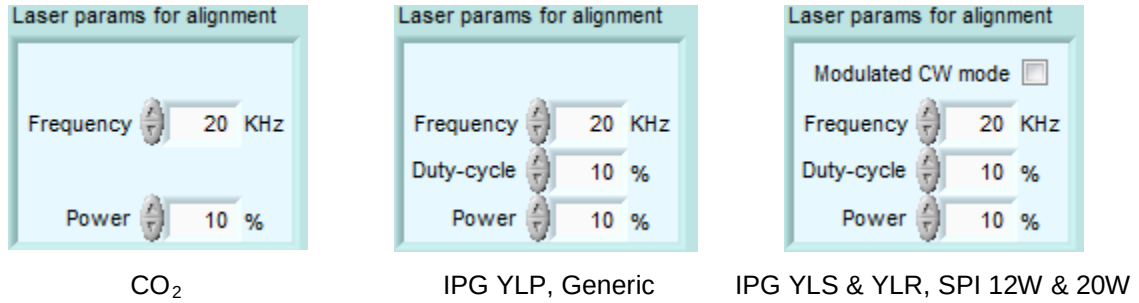


Figure 25: Laser Params

2. Set **Duration** to the number of seconds you want to laser before automatically turning off.
3. Entering “0” will turn the laser ON indefinitely.
4. Click the Go To XYZ button and enter 0, 0, 0 to aim the mirrors at the center of the field:

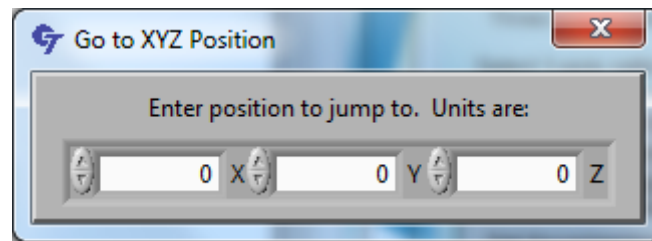


Figure 26: Go to XYZ Position



5. After parameters are set as needed, press the “Activate laser” button to fire the laser.
6. A confirmation pop-up will appear. Pressing **OK** will fire the laser for the set duration or until a manual OFF command is given (whichever comes first):

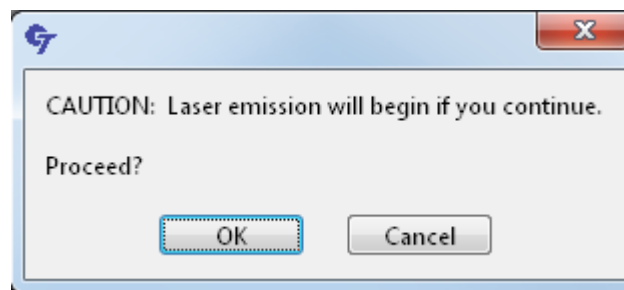


Figure 27: Confirmation Pop-up

- To turn off the laser, flashing **OFF** button or click any key on the keyboard.

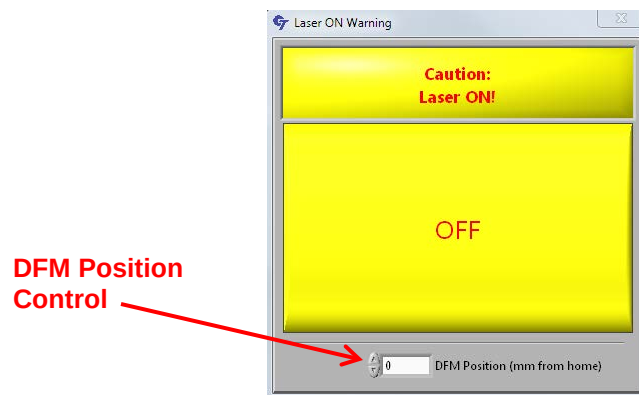


Figure 28: The Flashing OFF Button

- The control below the button (**DFM Position**) is used to set coarse focus for heads with variable field adjustment.

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Set Focus/Marking Params

CalWizard supports the following laser settings for different modes of operation:

- Marking – Medium power level to leave a clear mark on the media
- Focusing – Low power level to enhance variations in the mark due to focus quality
- Cutting – High power level to cut the marked pattern to be measured

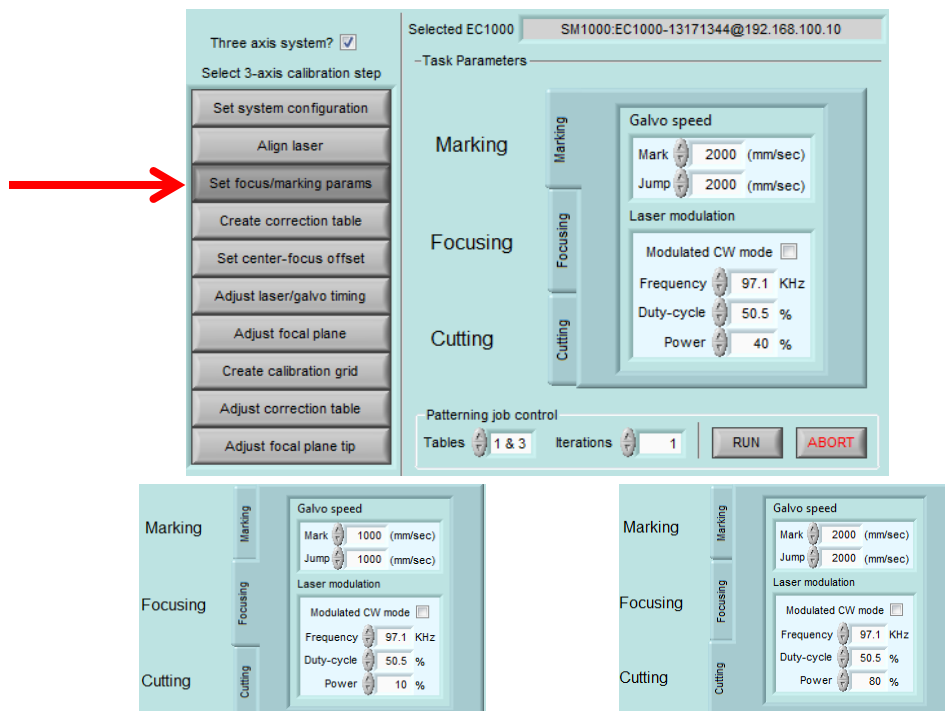


Figure 29: Focus / Marking / Cutting Parameters View

Notes:

1. Mark and Jump speed selections depend on the scan head model being used, as well as the application's accuracy and throughput requirements.
2. The availability of specific Laser controls will vary based on the laser type selected (see previous sections for details).

When done, save the configuration for future reference through the File menu.

To return to the procedure overview for 2-axis heads, click on [2-Axis Head Procedure Overview](#).

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Create Correction Table – 2-Axis Heads

The calibration process is an additive process: each calculation result is superimposed over the current corrections.

1. To eliminate any potential for error, all existing correction information is cleared when you open the Correction Table Editor by clicking the **Create correction table** button.

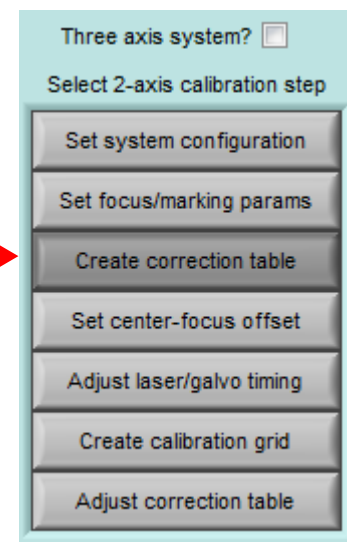


Figure 30: Create correction table button

2. To prevent erroneous clearing of information, the following confirmation pop-up is displayed:

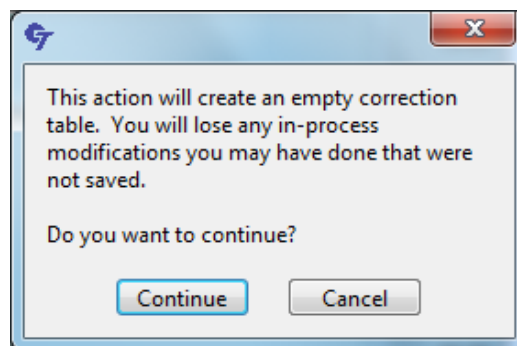


Figure 31: Confirmation Pop-up

- Once you press Continue in the Confirmation Pop-up, the correction table editor is displayed:

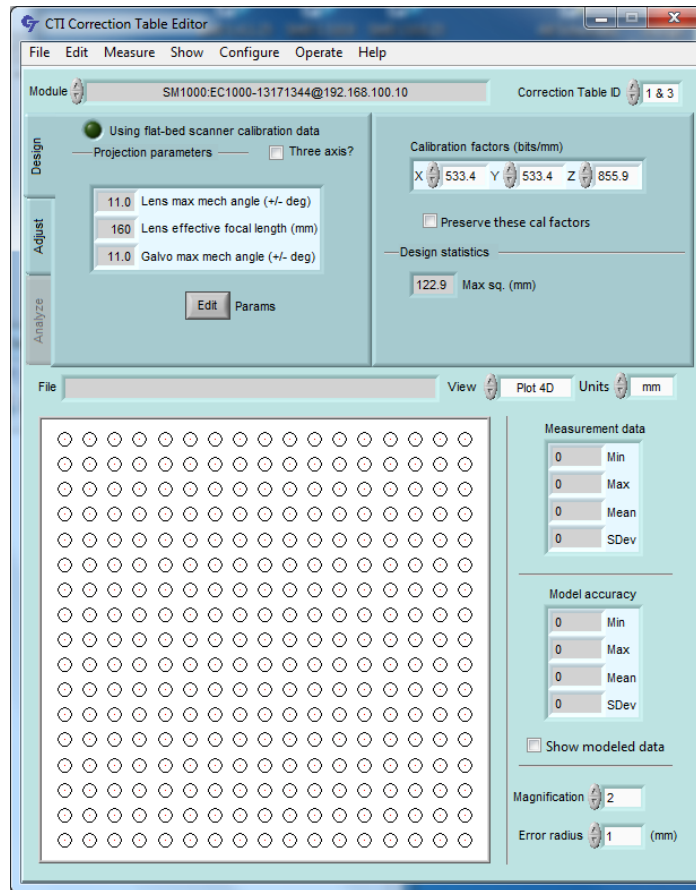


Figure 32: Correction Table Editor View

- Use the selectable tabs at the upper left region of the editor to define your table. You can edit the parameters of the head to reflect your actual situation.

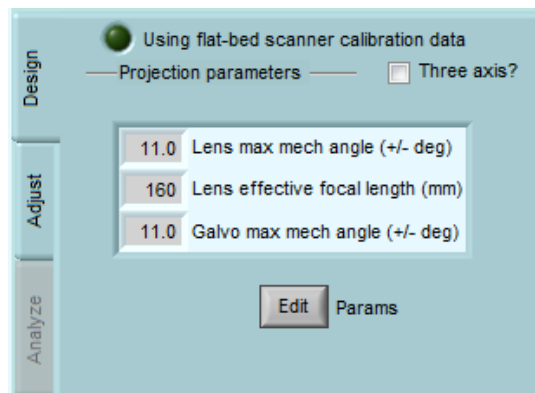


Figure 33: 2-Axis Design Parameters

5. The Projection parameters in the Design tab are set to the values you have entered previously and are used to synthesize a correction table based on your optical path geometry. To synthesize a baseline table, select **Edit | Synthesize baseline corrections**.

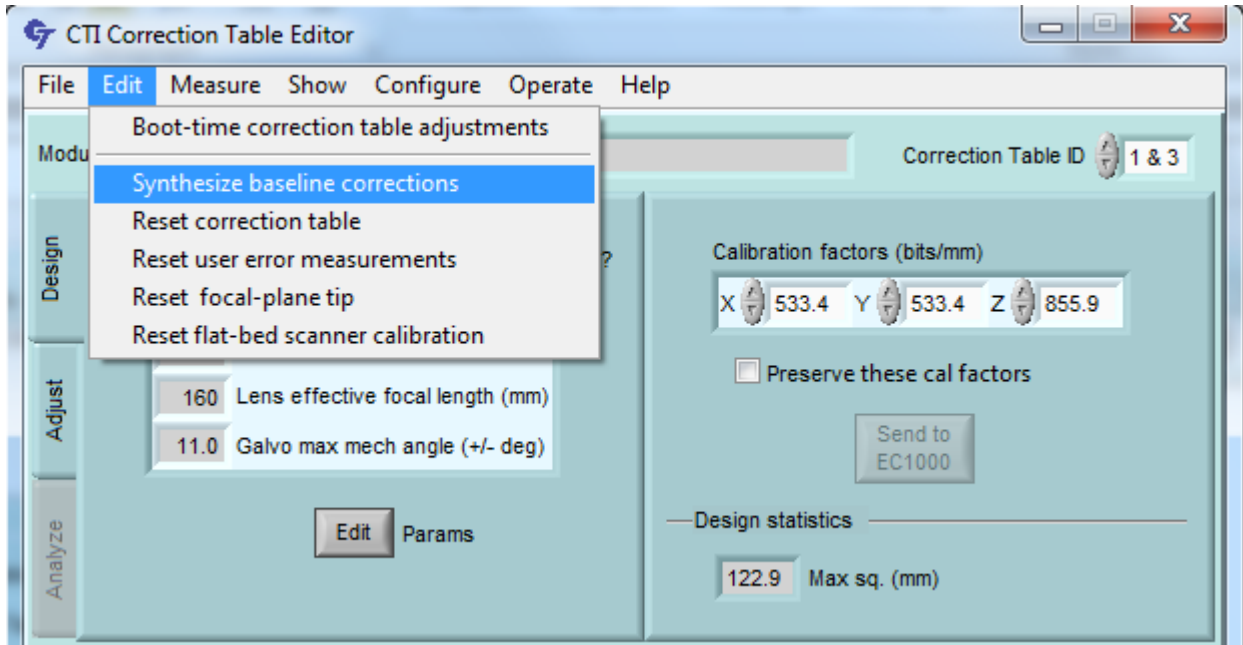


Figure 34: Edit | Synthesize baseline corrections

6. The editor will calculate pin-cushion distortion compensation that comes from the mirror spacing, and lens distortion compensation. It will automatically rescale the table contents and the calibration factors to optimize the use of the galvo command range. (This process is described in "Table Auto-Scaling" on page 76.) After this process is complete, the new table will be displayed. For an example, see the figure on the next page.

CTI Correction Table Editor

File Edit Measure Show Configure Operate Help

Module Correction Table ID 1 & 3

Design

☒ Using flat-bed scanner calibration data

Projection parameters ☐ Three axis?

Adjust

15.0 Lens max mech angle (+/- deg)

160 Lens effective focal length (mm)

11.0 Galvo max mech angle (+/- deg)

Analyze

Edit Params

Calibration factors (bits/mm)

X 561.8 Y 561.8 Z 855.9

☐ Preserve these cal factors

Send to EC1000

Design statistics

116.7 Max sq. (mm)

File View Plot 4D Units mm

Measurement data

0 Min

0 Max

0 Mean

0 SDev

☐ Show table data

Model accuracy

0 Min

0 Max

0 Mean

0 SDev

☐ Show modeled data

Magnification 2

Error radius 1 (mm)

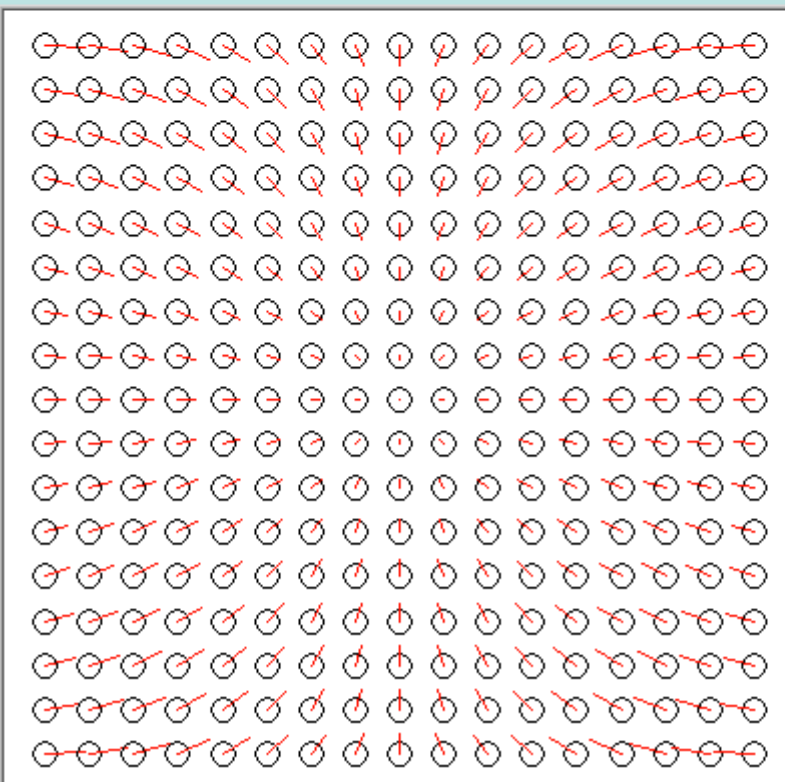


Figure 35: New Correction Table

7. If you change any of the parameters, the calibration factors will be recalculated and will override the values passed in when the editor was started.
8. Now, save the Correction Table.

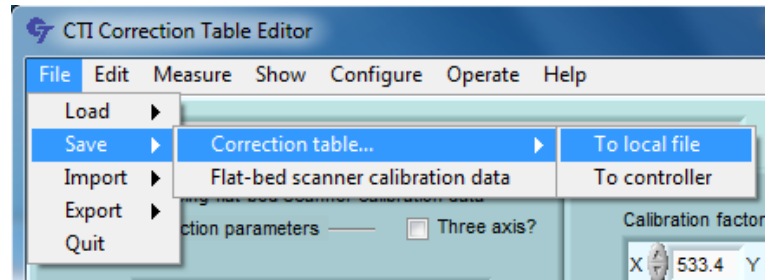


Figure 36: File | Save | Correction table... | To local file

9. Enter a description for the correction table and click OK:

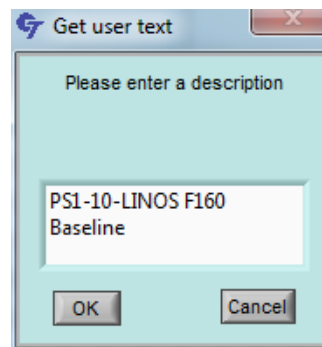


Figure 37: Get user text

10. Now enter revision information (if you wish) or leave it blank and click OK:

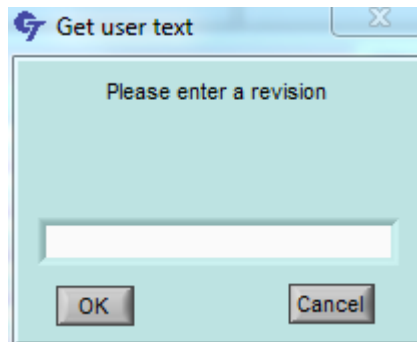


Figure 38: Enter a Revision

11. Next, specify a path and file name and click OK:

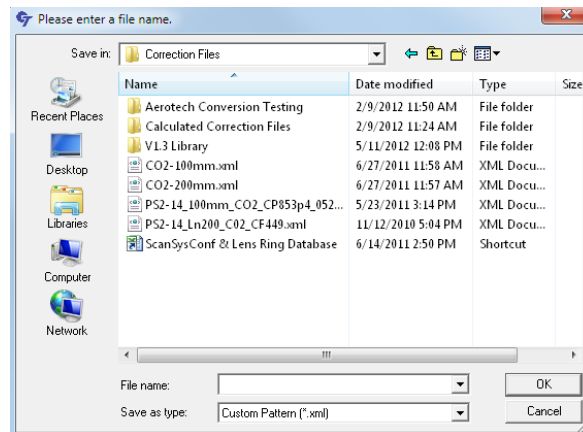


Figure 39: Specify a Path and File Name

12. Finally, use **File | Quit** to close the editor window. You'll be asked to select if to use the new correction in the future. Click OK / accept to all:

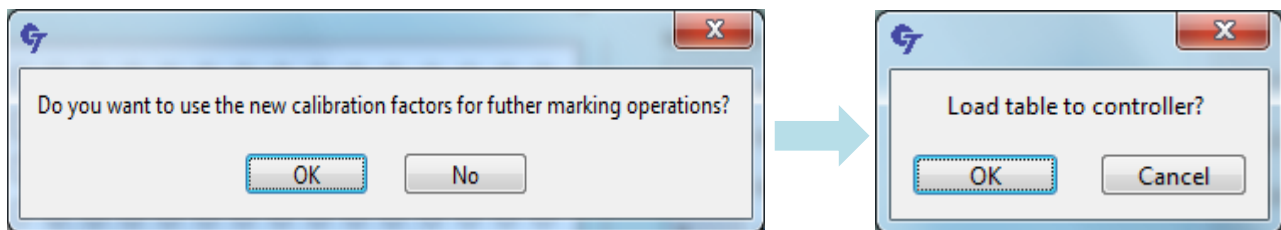


Figure 40: Close the Editor and Load the Table

To return to the procedure overview for 2-axis heads, click on [2-Axis Head Procedure Overview](#).

Create Correction Table – 3-Axis Heads

The calibration process is an additive process: each calculation result is superimposed over the current corrections.

1. To eliminate any potential for error, all existing correction information is cleared when you open the Correction Table Editor by clicking the **Create correction table** button.

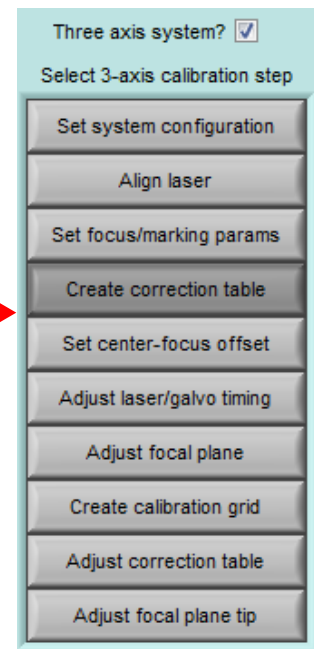


Figure 41: Create correction table button

- To prevent erroneous clearing of information, the following confirmation pop-up is displayed:

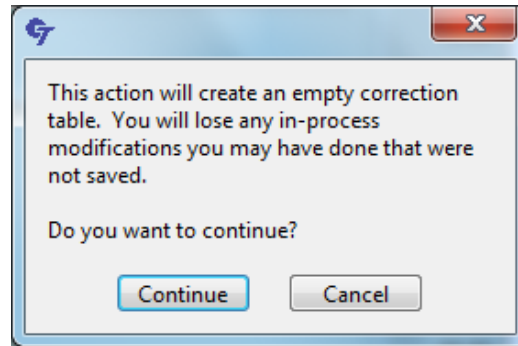


Figure 42: Confirmation Pop-up

- Once you press Continue, the correction table editor will appear:

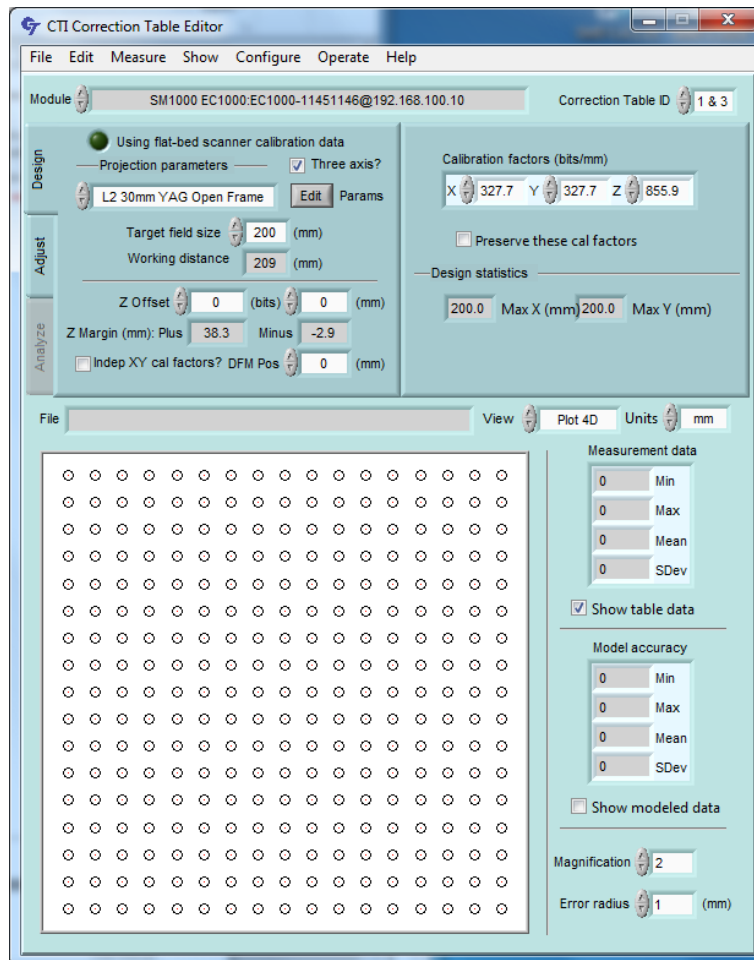


Figure 43: Correction Table Editor View

4. For 3-axis systems, a correction table is calculated based on the pre-set or custom head type that was set in the Set system configuration.

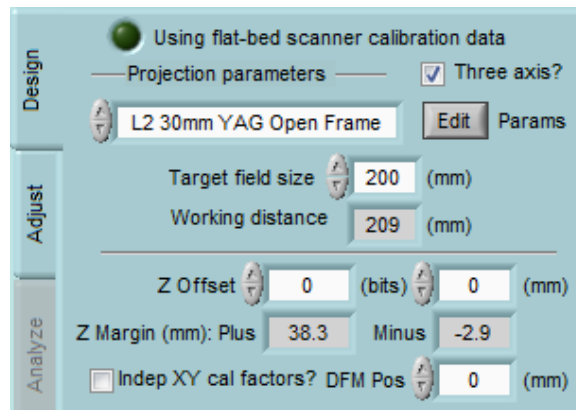


Figure 44: 3-Axis Design Parameters

5. Set the Working distance field to be 5% larger than the actual field you intend to use. This will ensure that the features of the calibration grid used later will fit within the useable field.
6. Once the desired Working distance field size is defined, the software will calculate the theoretical working distance required. The default is for X & Y calibration factors to be set to the same value to produce a square imaging field, but they can be set independently to allow for rectangular fields (limited by the Y field dimension).
7. Z Offset is used for electrical fine tuning of the nominal position of the focusing mirror to achieve a good focus at the center of the field (see "Set Focus/Marking Params" on page 23). The Z Margin shows the available travel distance beyond field flattening for 3D operation.
8. For applications that require varying work distance (3D Marking), the Z offset can be adjusted to modify the margin available beyond the range used for field flattening.
9. Lastly, for systems with varying field size (motorized Z axis), a "Home" position is required for the DFM (Dynamic Focusing Module).
10. If you change any of these parameters, the calibration factors will be recalculated and will override the values passed in when the editor was started.

11. To synthesize a baseline table, use the Edit menu.

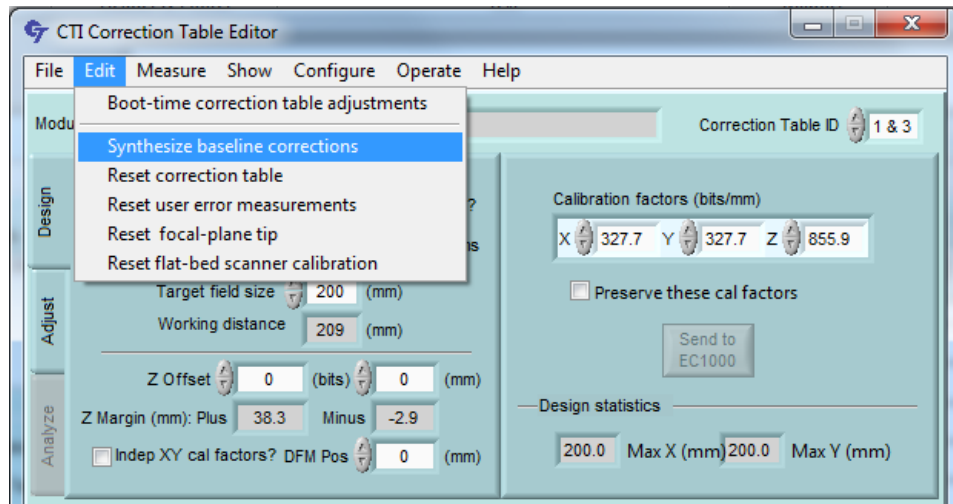


Figure 45: Edit | Synthesize baseline corrections

12. The editor will calculate pin-cushion distortion compensation that comes from the mirror spacing. It will automatically rescale the table contents and the calibration factors to optimize the use of the galvo command range. After this process, the new table will be displayed.

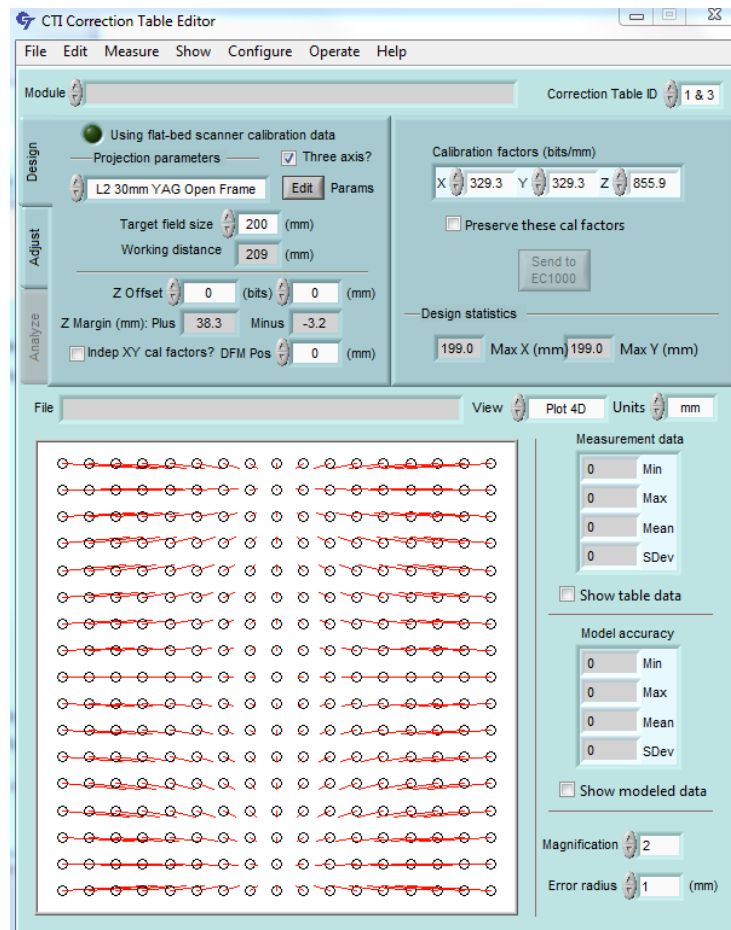


Figure 46: Correction Table Editor

13. Now, save the Correction Table.

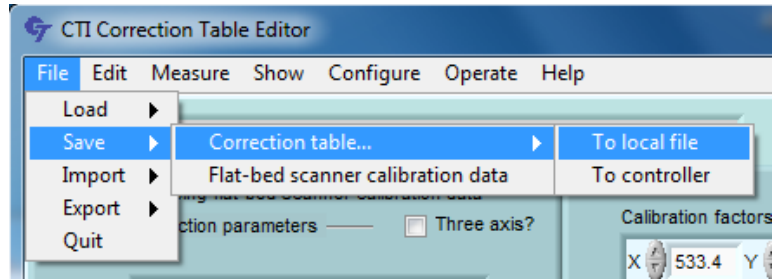


Figure 47: File | Save | Correction table... | To local file

14. Enter a description for the correction table and click OK.

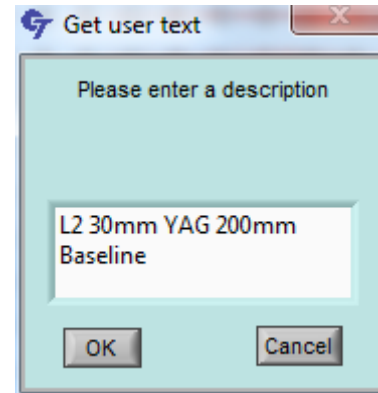


Figure 48: Description for the Correction Table

15. Now enter revision information and click OK.

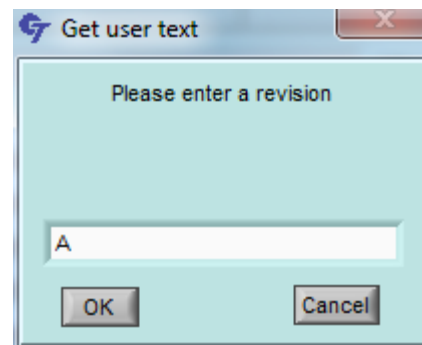


Figure 49: Revision Information

16. Next, specify a path and file name and click OK.

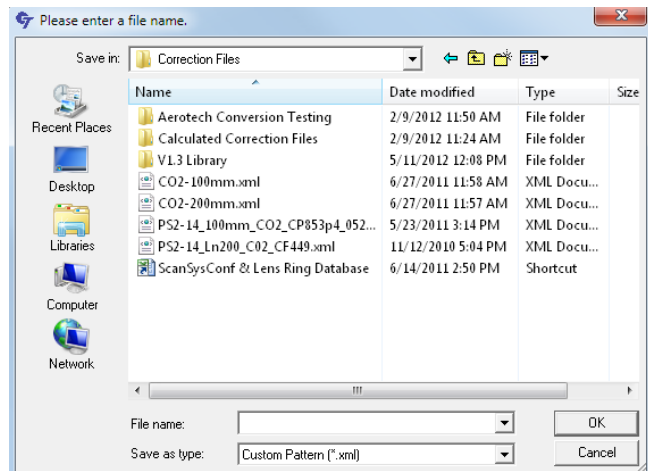


Figure 50: Specify a Path and File Name

17. Finally, use **File | Quit** to close the editor window. You'll be asked if you want to use the new calibration factors for future marking operations. Then you'll be asked if you want to load the table to the controller. Click OK in each dialog box.

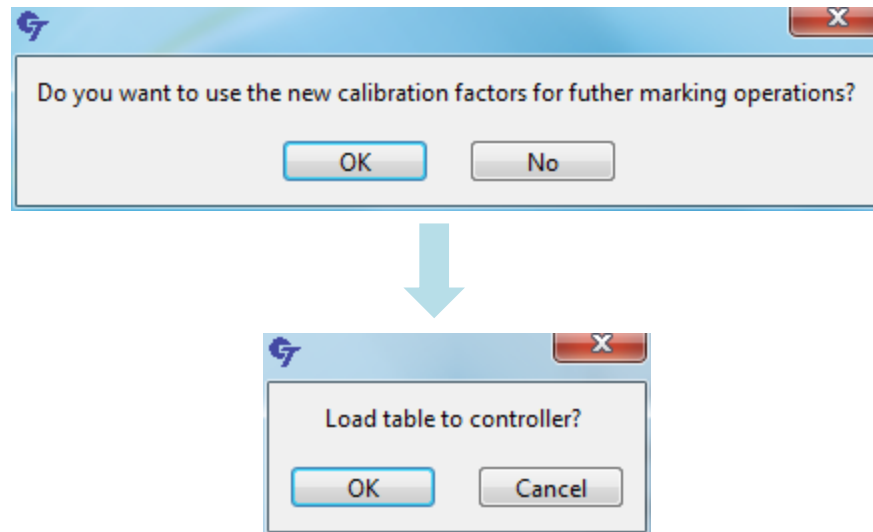


Figure 51: Close the Editor and Load the Table

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Set Center-Focus Offset – 2-Axis Heads

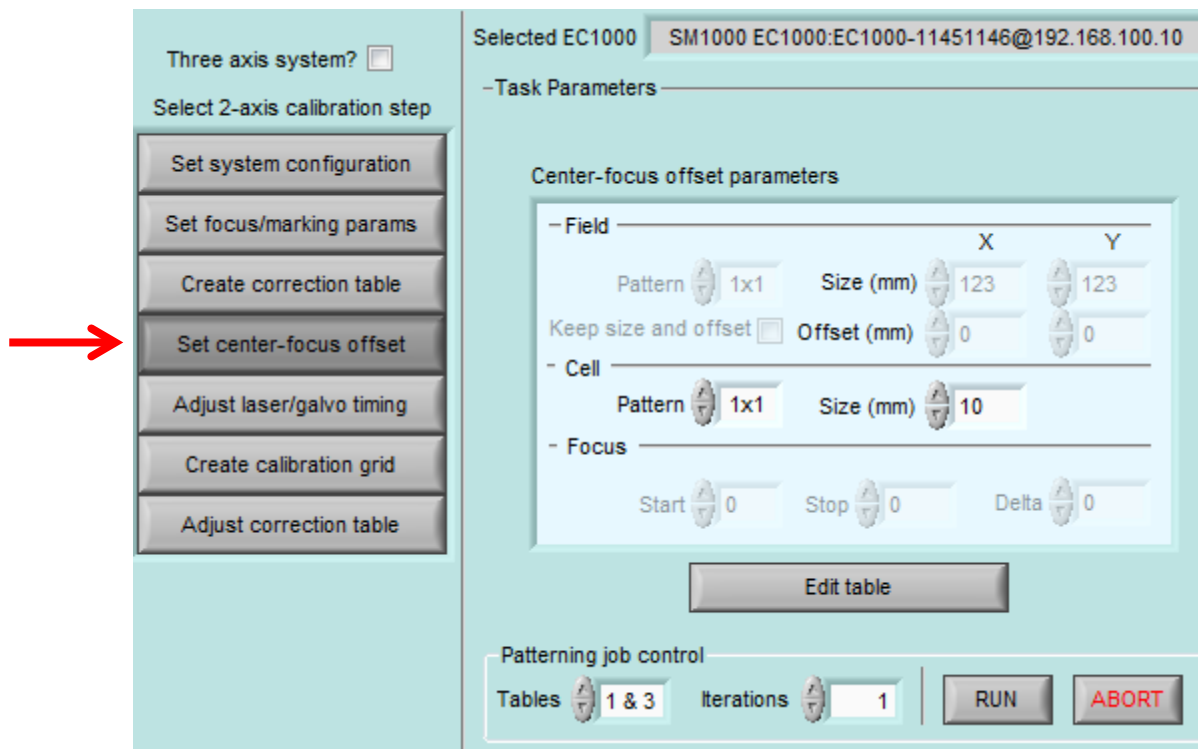
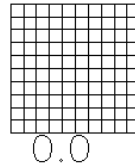


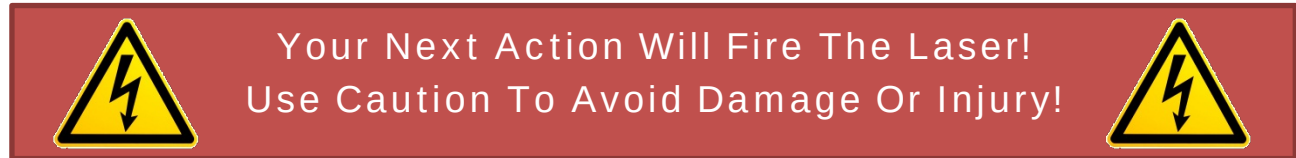
Figure 52: Set Center-Focus Offset View

In this step, the system is adjusted to achieve a focused beam at the center of the field.

The optical path through the head's mirrors and the lens is fixed, so the distance between the head and the target surface is adjusted to achieve a focused grid image.



1. Define the size of the grid.



2. Click the Run button to mark the grid.
3. Adjust the work distance and repeat until you get a well-focused mark.

To return to the procedure overview for 2-axis heads, click on [2-Axis Head Procedure Overview](#).

Set Center-Focus Offset – 3-Axis Heads

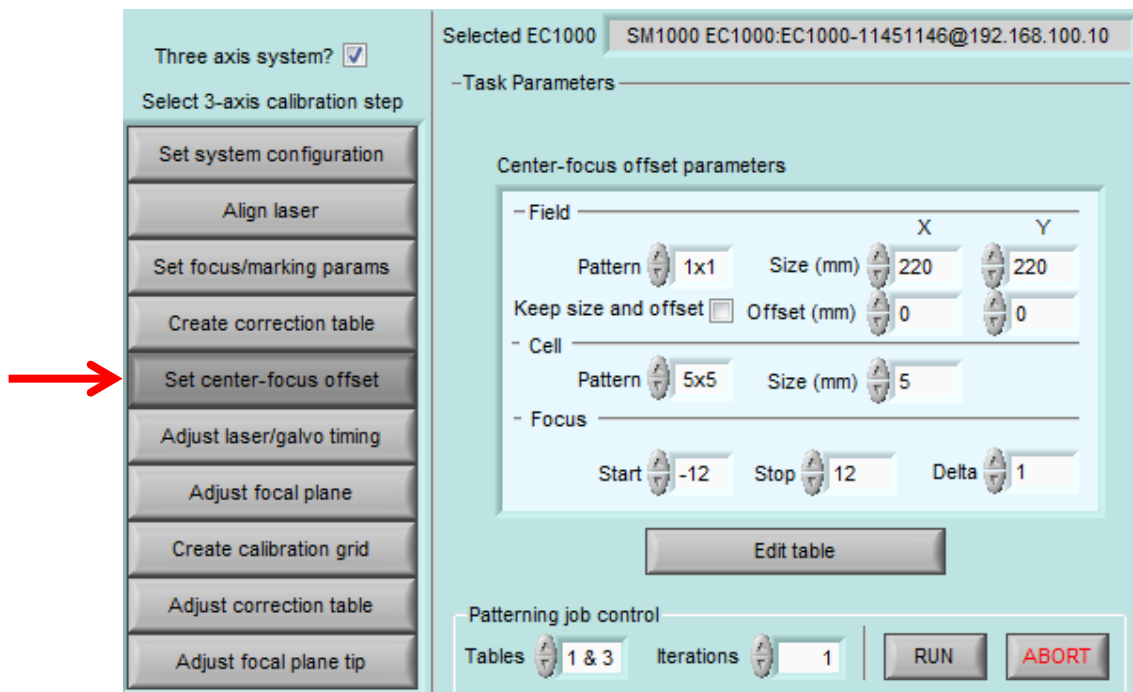
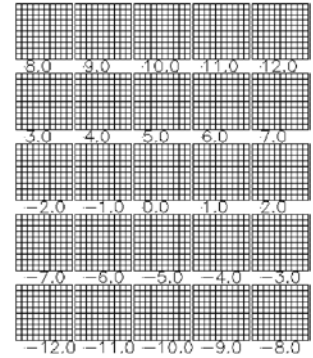


Figure 53: Set Center-Focus Offset View

In this step, the system is adjusted to achieve a focused beam at the center of the field.

Coarse adjustment of the nominal focal length is done by changing the DFM module's distance to the XY block. Position the DFM module so you get a mark at the center of the field (regardless of its quality).



Fine adjustment of the nominal focal length is done by updating the Z-Axis offset value.

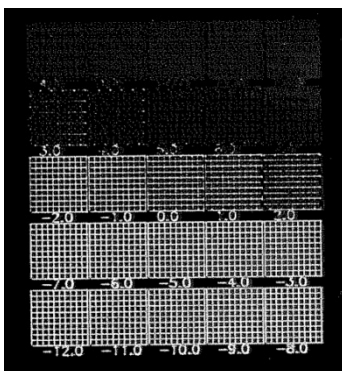
1. For this step of the process, leave the Field portion without change, and set the Cell values for a 5x5 Focusing Array (as shown on the right).
2. Then set the Focus portion values to define the start offset and stop offset. The software will automatically calculate the step size that the DFM is moved before each of the images is marked. Alternately, you can set the start offset and step size and the stop offset will be calculated.



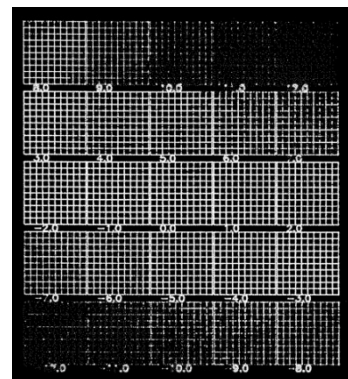
Your Next Action Will Fire The Laser!
Use Caution To Avoid Damage Or Injury!



3. Click the Run button and wait for the whole pattern to be marked.
4. Observe the resulting mark. With large enough steps, the mark quality will vary as the offset of the DFM is changed during marking.
5. In a poorly-focused system, the mark quality will be poor on one side of the array and better on the opposite side (see image on next page).
6. In a well-focused system, the mark quality will start very poor, improve towards the center of the array, and then deteriorate again.



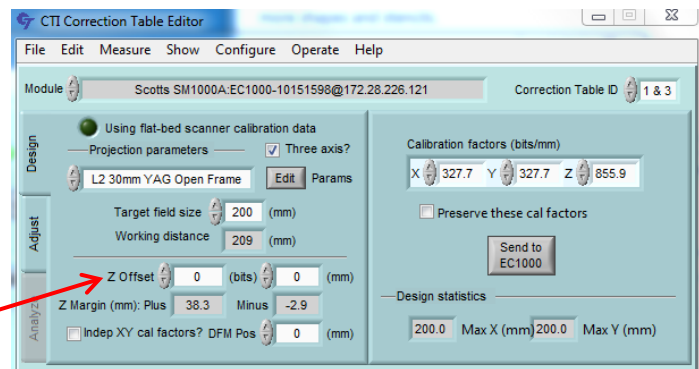
System out of focus



System in focus

7. Open the Correction Table Editor by clicking the Edit table button.
8. Identify the offset value that resulted with the best focused beam (based on the individual grid's marked value), and **subtract** it from the current Z Offset value.

Z Offset value



F
Figure 54: Z Offset Value

9. Repeat the process until you achieve a good focused image at the central grid (0.0 offset). Reduce the start offset and step size to get better granularity of the offset value.

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Adjust Laser/Galvo Timing

Now that the laser is focused, it is time to optimize laser and scanner delays under **Adjust laser/galvo timing**.

Do not skip this step, as low-quality marking of the grid might cause the upcoming measurement and analysis to fail.

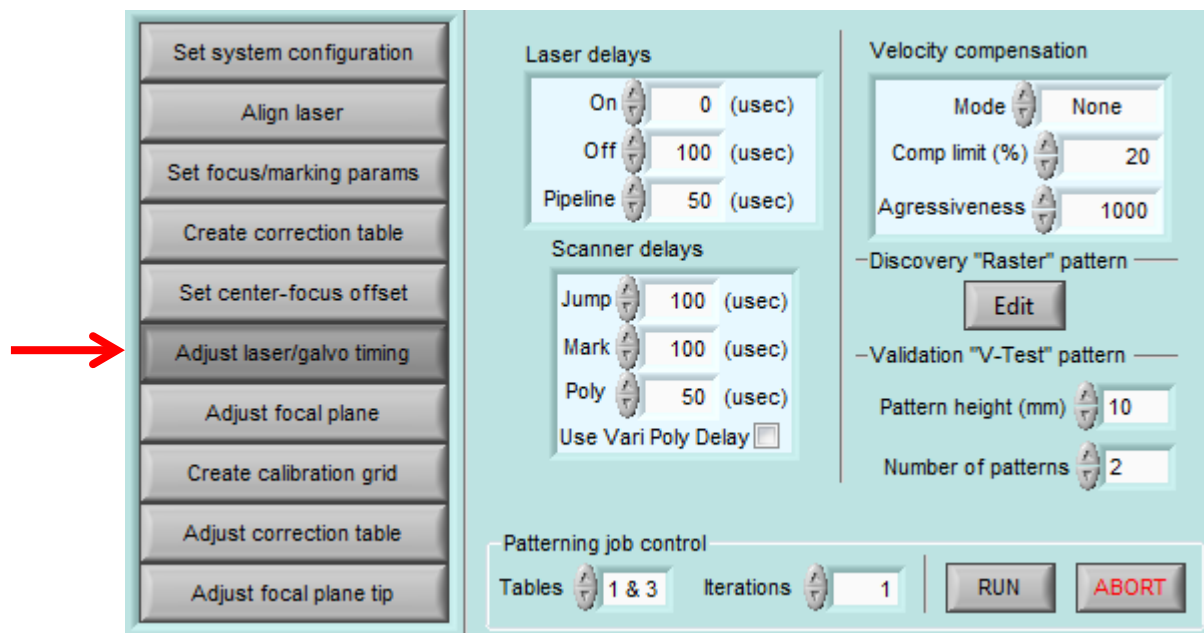


Figure 55: Set Laser/Galvo Timing View

Different lasers require different settings for the Pipeline delay¹, Laser On delay, and Laser Off delay, while application considerations may require different values for the Mark, Jump and Polygon delays (referred to as “Application Delays”). Many of the delays are interdependent, so changing one may affect another, resulting in a long trial-and-error process until you find the values you need. Cambridge Technology has developed a process to guide you through proper, streamlined set-up of the various delays for your specific laser and application needs.

1. The process starts with a coarse adjustment to get the parameters close to the required values, followed by a much finer adjustment to optimize those values. For the coarse adjustments, use a mark size that can be seen easily and a speed 30%-50% higher than you intend to use for the application. For the finer adjustments, the pattern size should be similar to your job, while the speed is adjusted as needed.
2. The Laser On and laser Off delays are better set with a higher speed than you intend to use for the application, as they may no longer be valid when the speed is increased. However, laser timing will improve as the speed is decreased, ensuring better accuracy in turning the laser on and off.
3. The same is not true for the Application delays. As you mark faster, you may need to increase the application delays to maintain the quality of the mark, while as you slow down you might create excessive delays that will either burn-in or waste time idling at some points. For that reason, Laser delays are set first at a higher speed, and then the Application delays are set at the intended operational speed.

Setting Laser Delays

To set the Laser delays, a Discovery “Raster” pattern is used.

An array of patterns is defined with Pipeline delay kept fixed per column and increases between columns, while Laser Off Delay kept fixed per row and increases between rows:

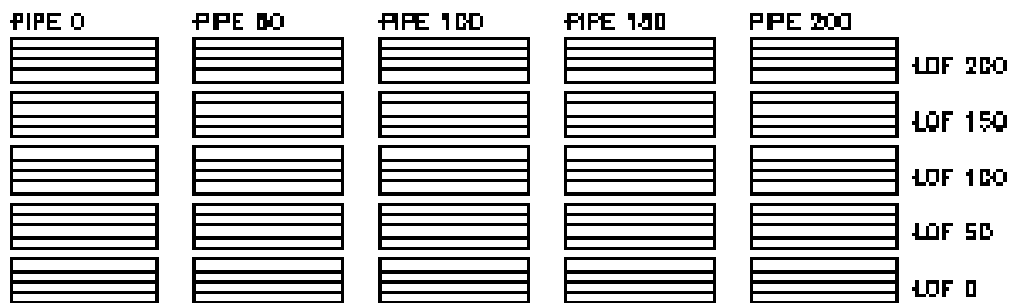


Figure 56: Discovery “Raster” Pattern

1. To set Laser Delays shown in Figure 56, do the following:
 - a. Set Laser On delay to 0.
 - b. Set Jump and Mark delays to a large value ($\geq 1,000$).

¹ Pipeline delay is used to delay the laser control signal relative to those of the Galvo, for better synchronization.

- c. Set Velocity Compensation mode to “None” (even if you intend to use it!).
- d. Click on the “Edit” button to set up a Discovery “Raster” pattern.

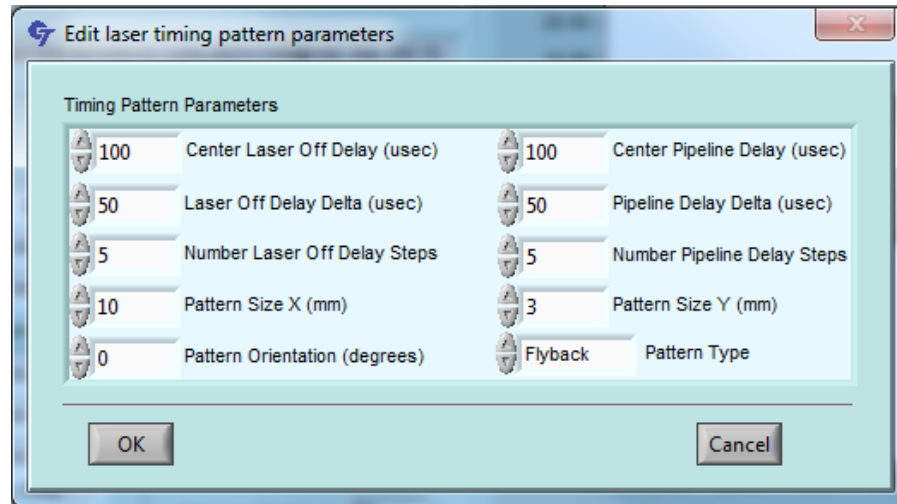


Figure 57: Discovery “Raster” Pattern Setup

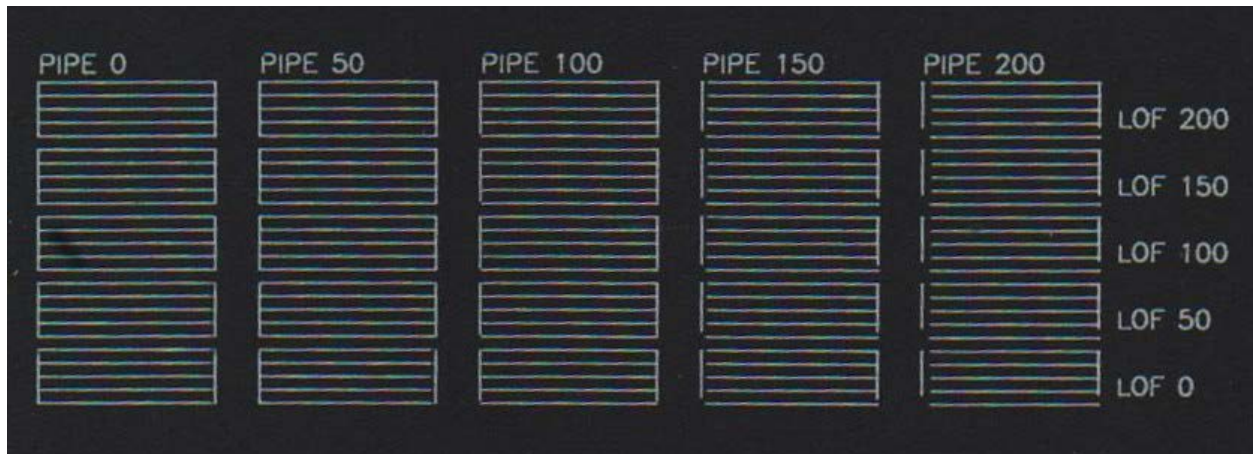
2. The array is defined using the following parameters, as shown in Figure 57:
 - Center value for each delay (use 700 for 3-Axis heads and 100 for 2-Axis heads)
 - Delta value between columns / rows (Start with 50 and adjust as needed)
 - Number of columns / rows
 - Width and length of each pattern in the array
 - Angular orientation of the array
 - Set the pattern type to flyback for this first mark



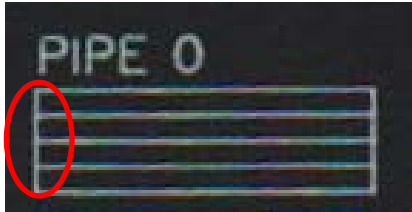
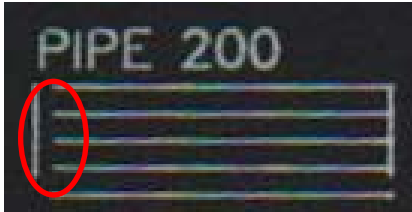
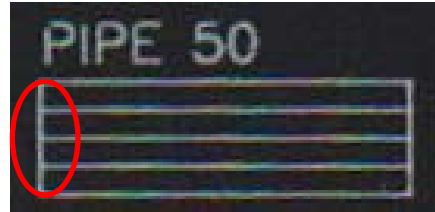
Your Next Action Will Fire The Laser!
Use Caution To Avoid Damage Or Injury!



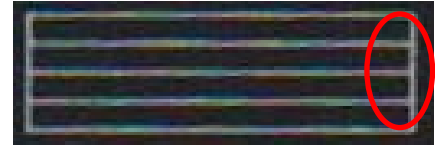
3. Click the Run button to mark the pattern.



4. Once the pattern is marked, examine across the columns, left to right, looking at the left edge to find the best Pipeline Delay value (i.e., the one where the horizontal lines meet the left vertical line but are not over-burnt).

Over-burned – Too short	Not meeting – Too long	Just right
		

5. In the best Pipeline Delay column, examine from bottom to top the right edge looking where the corner is well connected and not over-burnt. The best row identifies the best Laser Off Delay.

Not meeting – Too short	Over-burned – Too long	Just right
		

6. In the above example, the best values will be Pipeline Delay = 50 μ s and Laser Off Delay = 100 μ s. Set these values as your new center values, reduce the delta to get better resolution, and mark again. If you intend to use Velocity Compensation, change its mode to the desired one and repeat the process several times to achieve ideal settings.

Setting Application Delays

To set the Application delays, we will be using the “V-Test” Pattern on the right.

The V-Test pattern is a series of marks and jumps that is set up to highlight the effect of the various delays. It contains a small square, two “V” shapes (one pointing down and the other pointing up), and two lines connecting the tip of one “V” with the middle of the other at both the top and bottom. To avoid confusion due to random irregularities, two or three V-Test patterns should be used (as seen in the image below).

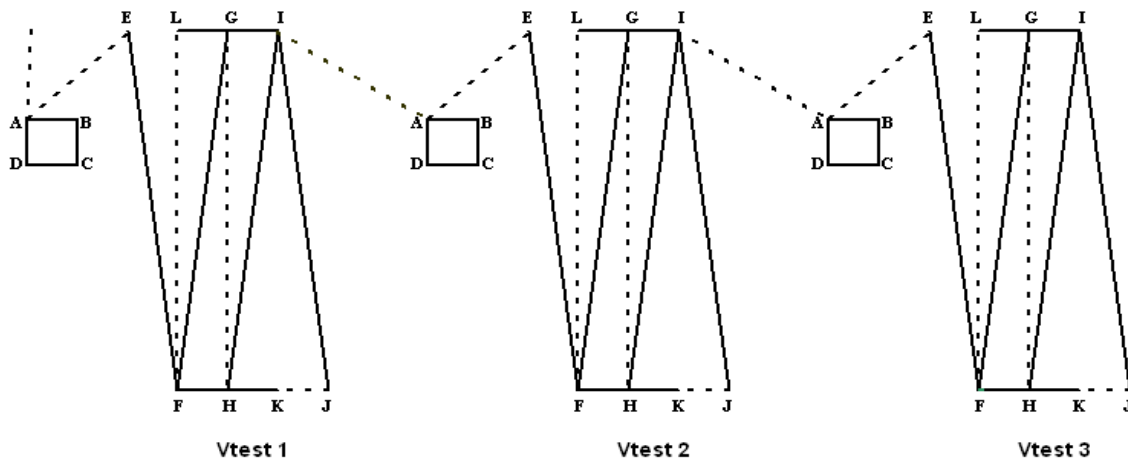
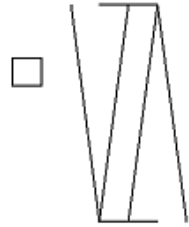


Figure 58: V-Test 3-Pattern Array

To properly use the process, you need to know the path the laser follows for each jump and mark. For that, we will label each point where a delay might be observed with a letter, and number each of the V-Test patterns in the array. We will also depict a jump as a dashed line and a mark as a solid line.

During the process discussion, a reference to segment EF2 relates to the marked vector that is the left side of the first V in the middle (2nd) pattern. Following the same guidelines, square ABCDA1 refers to the start point, path, and end point of the leftmost square (drawn from point A to point B to Point C to point D and Back to Point A, in Vtest1). It may help to print Figure 58 (“V-Test 3-Pattern Array”) on page 41, and Figure 59 (below), for reference in the following few pages.

- | | | |
|-----------------------|------------------------|------------------------|
| 1. Jump to A1 | 11. Jump to point A2 | 21. Jump to point A3 |
| 2. Mark square ABCDA1 | 12. Mark square ABCDA2 | 22. Mark square ABCDA3 |
| 3. Jump to point E1 | 13. Jump to point E1 | 23. Jump to point E3 |
| 4. Mark “V” EFG1 | 14. Mark “V” EFG2 | 24. Mark “V” EFG3 |
| 5. Jump to point H1 | 15. Jump to point H2 | 25. Jump to point H3 |
| 6. Mark “V” HIJ1 | 16. Mark “V” HIJ2 | 26. Mark “V” HIJ3 |
| 7. Jump to point K1 | 17. Jump to point K2 | 27. Jump to point K3 |
| 8. Mark segment KF1 | 18. Mark segment KF2 | 28. Mark segment KF3 |
| 9. Jump to L1, | 19. Jump to L2, | 29. Jump to L3, |
| 10. Mark segment LI1 | 20. Mark segment LI2 | 30. Mark segment LI3 |

Figure 59: V-Test Pattern Sequence

Adjust Pattern height and number for the V-Test. (If you want to use the default values, change one and then change back to get the pattern displayed on the screen).

With the Laser delays set with the results of our previous test, we'll start to adjust the Application delays.



1. Click the Run button to mark the pattern.
2. Make coarse adjustments of application delays:
 - a. Observing the squares ABCDA2 & ABCDA3, look for quality issues in the B, C & D corners. If you initially set this delay to zero, it is likely to be too short as shown in the image on the left.

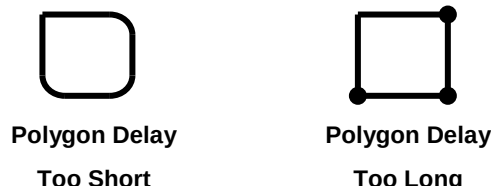


Figure 60: Polygon Delay Defects

- b. If the delay is set too short, the three corners will be rounded because the mirrors will not have enough time to reach those points. If the delay is set too long, there will be burned-in spots at three corners as the mirrors dwell on these points for too long. The fourth is affected by the Jump delay at the start and the Mark delay at the end and will be adjusted next.
- c. It is now time to adjust the Mark delay—the delay at the end of a mark sequence before the laser is turned off for a jump. The effects of this delay are easily observed at point J of the V-Test pattern. If you initially set this delay to zero, it is likely to be too short as shown in the image on the left.

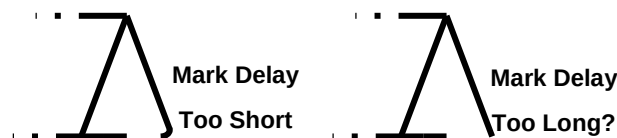


Figure 61: Mark Delay Defects

- d. If the Mark delay is too short, the line at the end of the V will be bent in in the direction of the jump that follows; if the Mark delay is too long, the end of the V might be burned-in. With the Laser Off delay set properly, no noticeable artifact is produced, although the mirrors dwell there for too long a time. This is not a concern just yet, as it will be properly handled during the fine adjustment stage.

- e. Adjust the Mark delay to produce a properly marked V shape.

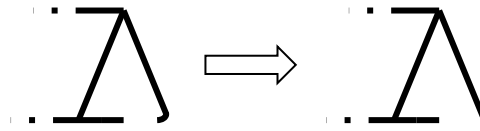


Figure 62: Mark Delay Adjustment

- f. Lastly, we'll adjust the Jump delay—the delay at the end of a jump. The effects of this delay are easily observed at point E of the V-Test pattern. If you initially set this delay to zero, it is likely to be too short, resulting in the image shown on the left.

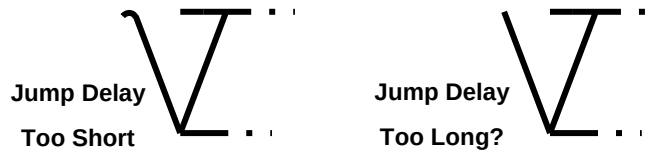


Figure 63: Jump Delay Defects

- g. If the Jump delay is too short, the line at the start of the V will be bent in in the direction of the jump that preceded it. If the delay is too long, the start of the V might be burned in. However, with the Laser On delay set properly, no noticeable artifact is produced, although the mirrors dwell there for too long a time. This is not a concern just yet, as it will be properly handled during the fine adjustment stage.
- h. Adjust the Jump delay to produce a properly marked V shape.

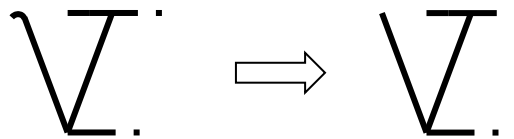


Figure 64: Jump Delay Adjustment

3. Make fine adjustments of laser delays:
 - a. Now that the delays are set to produce a reasonable mark, it is time to set them closer to our required parameters.
 - b. Start by setting the pattern size to a size similar to the job you want to run.
 - c. Set the speed to be 10%-20% higher than the speed you expect to use for the application, as higher speed will exaggerate deviations you may not have noticed before.
 - d. Observe points G and H of the pattern, as these are locations where separate marks should touch each other, and will often show small timing issues not noticed in other places.

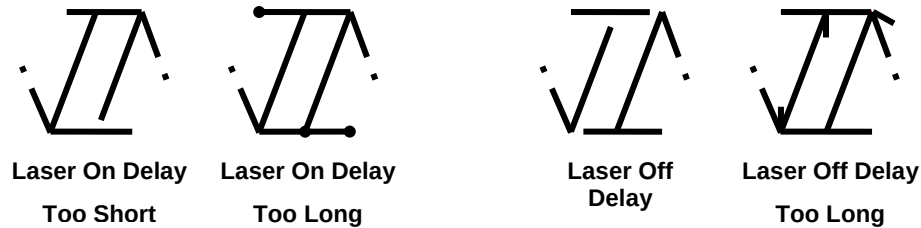


Figure 65: Laser Delays Fine Adjustment

- e. To adjust, reduce the value of the relevant delay until a defect is visible, then increase it slightly to correct the defect. Do not increase the value too much as no defect will be noticeable but the mirror will dwell for too long a time, increasing the job execution time for no good reason.
- f. Ignore points F and I as they may be affected by the Polygon delay as well as the Mark Delay.



Figure 66: Polygon Delay and Mark Delay Are Too Short

4. Make fine adjustments of application delays:
 - a. Now that the Laser delays are set properly, let's optimize the Application delays.
 - b. Set the speed to what you intend to use for the application. To maintain the mark's quality, Mark delay, Jump delay and Polygon delay may require adjustment when the speed changes. The Laser delays were set at a higher speed, so they will get more precise even as you slow down the speed.
 - c. Once again, we'll start with the Polygon delay.
 - d. Set the Mark delay to a value 25% higher than its current value. This will ensure that segments KF and LI end at points F and I respectively as the mirrors have plenty of time to reach the end of those vectors before the next jump.

- e. Observe points F and I for the position of the tip of each V, relative to the segment it should touch. Adjust the Polygon delay until the tips of the V's touch those segments and no burn-in occurs.

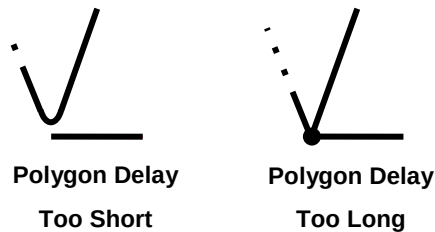


Figure 67: Polygon Delay Fine Adjustment

- f. Next, restore the Mark delay value to the coarse adjustment value (20% less than the current one) and then continue to reduce it until the segment's edge no longer touches the tip of the V. Now, increase it slightly to correct the defect. Do not increase the value too much as no defect will be noticeable but the mirror will dwell for too long a time, increasing the job execution time for no good reason.



Figure 68: Mark Delay Fine Adjustment

- g. For Jump delay fine adjustments, repeat the above process while observing point H's connection to the middle of the segment. Reduce the Jump delay value until a defect can be seen, and then increase it slightly to correct the defect. Once again, avoid increasing the value too much to prevent the mirror from dwelling for too long a time, increasing the job execution time for no good reason.

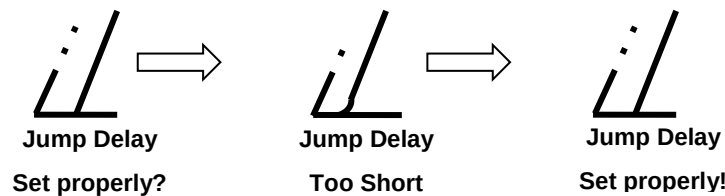


Figure 69: Jump Delay Fine Adjustment

5. At this point, Laser delays should all be set properly and Application delays will be proper for a given type of job. For applications with very stringent quality requirements, final adjustments should be done with the actual job you want to mark. Keep in mind that some settings are interrelated, so changes to one delay can affect others. If things go wrong, repeat the fine adjustments step to correct them.

To return to the procedure overview for 2-axis heads, click on [2-Axis Head Procedure Overview](#).

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Adjust Focal Plane – 3-Axis Heads

With good marking parameters, we can now adjust the focal plane in a 3-Axis system to ensure a focused beam over the entire field.

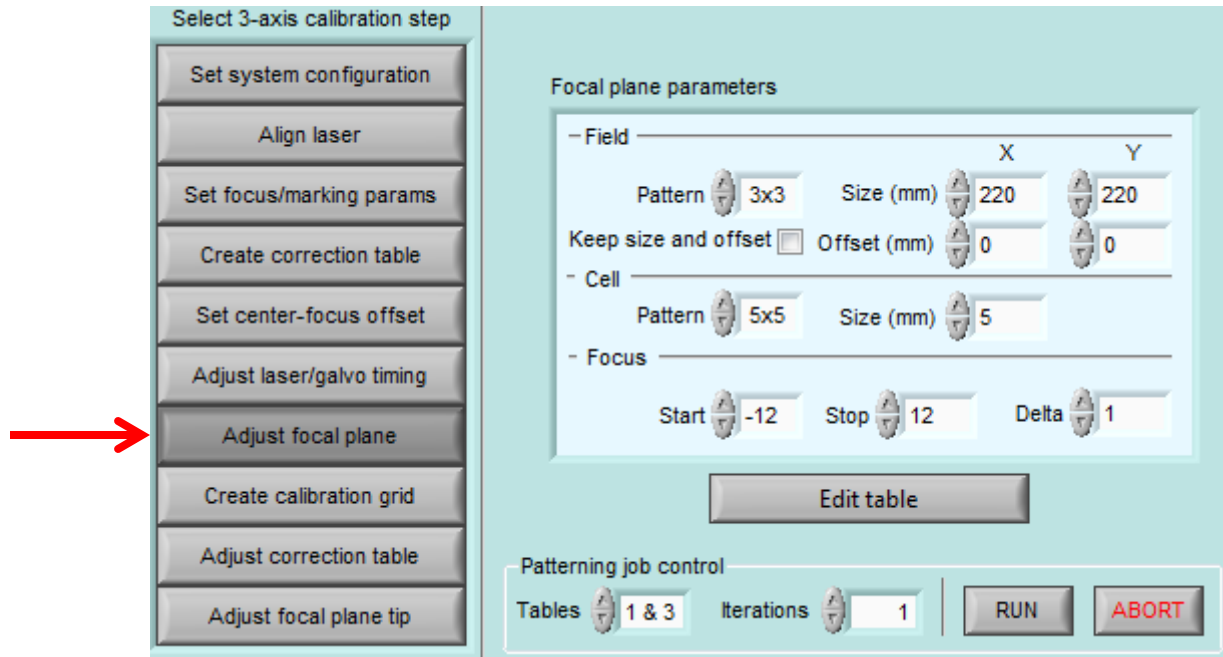


Figure 70: Adjust Focal-Plane View

Similarly to the Center Focus step, the software uses the 3x3 or 5x5 Focusing Array, but this time it is positioned not only at the center of the field, but also along the edges and in the corners.

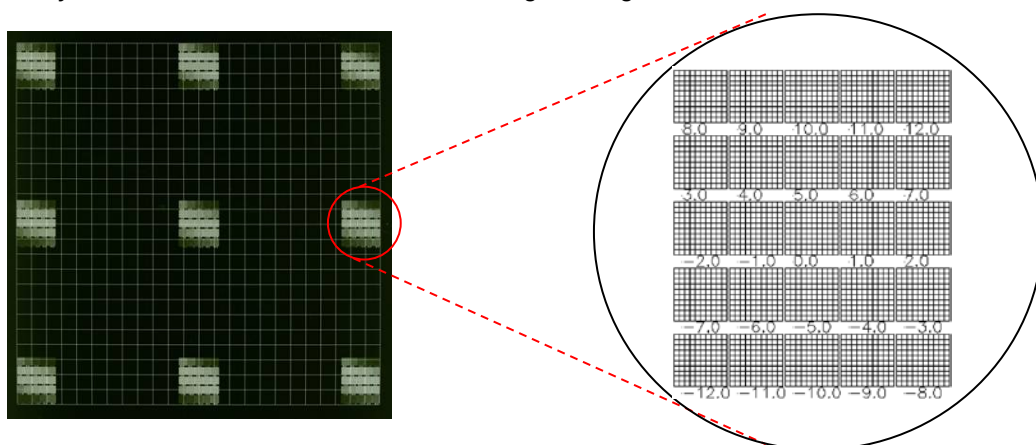


Figure 71: Adjust Focal-Plane Pattern

Once again, the 3rd axis (DFM) is moved before marking each of the grid's images in each of the locations. The Z calibration factor (for the DFM) is adjusted to achieve a *reasonably* focused beam all over the field.



1. Click the Run button to get the pattern marked.
2. Now click the **Edit table** button to open the Correction Table Editor, and then select **Measure | Collect focal plane data**.

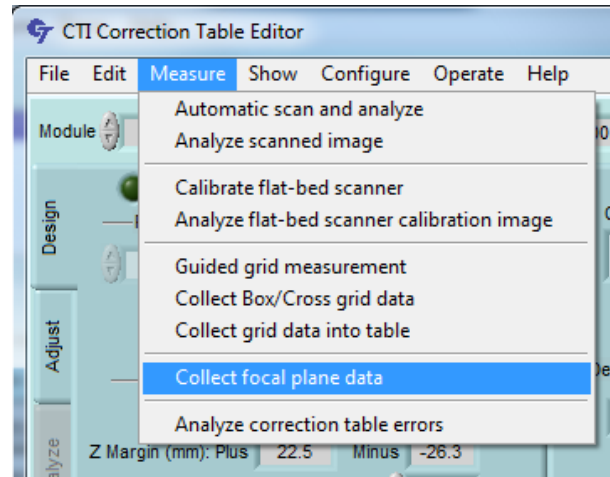


Figure 72: Measure | Collect focal plane data

3. For each Focusing array location, discern the offset value that results in a focused beam, and enter it into the corresponding field in the window.

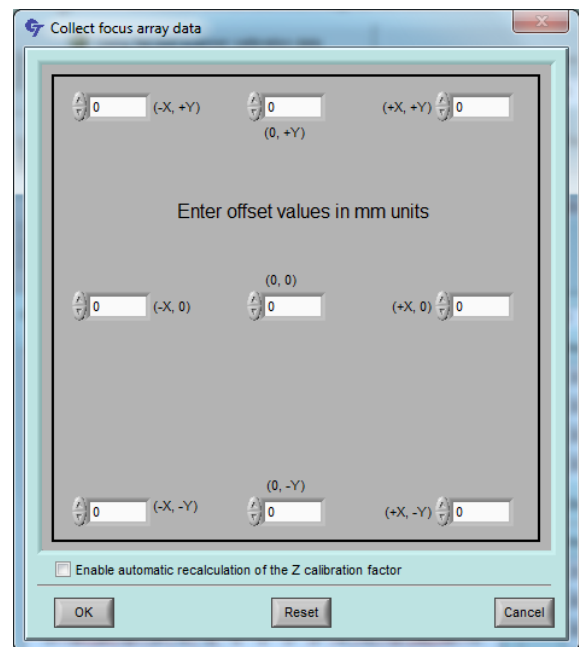


Figure 73: Focal Plane Data Entry Window

4. Check the checkbox at the bottom to enable the software to recalculate the Z calibration factor that will compensate for non-flatness across the marking field.

Note: The information entered through this tool is accumulative, so while the presented values are reset to zero every time you open the tool, previously applied corrections remain in effect.

3D Compensation

If you are planning to mark on a plane different than the one on which you perform the calibration, the conical nature of galvo scanning will cause a dimensional change in X & Y due to the change in Z. The Calibration Wizard can calculate a compensation for this distortion based on the head's geometry. To enable the option, go to **Configure | 3D Compensation**.

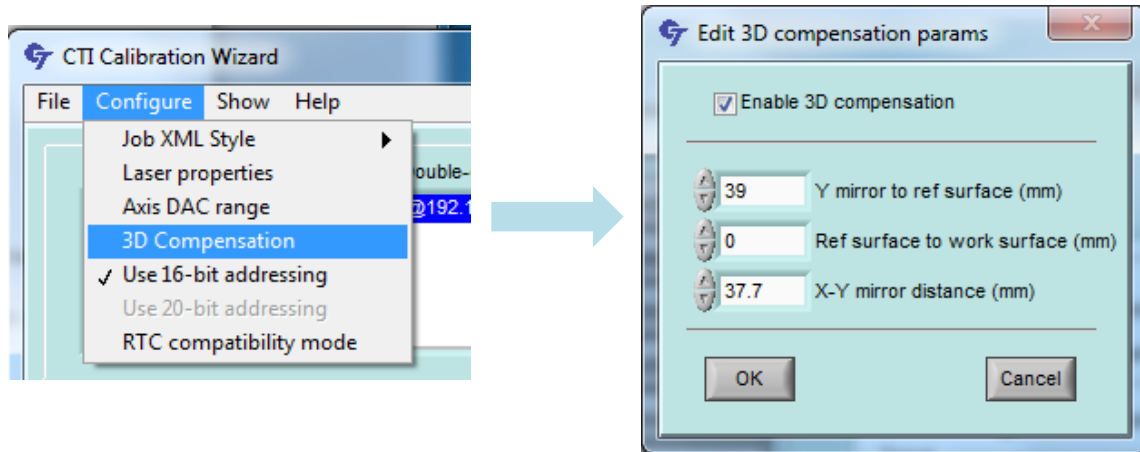


Figure 74: 3D Compensation Parameters

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Create Calibration Grid

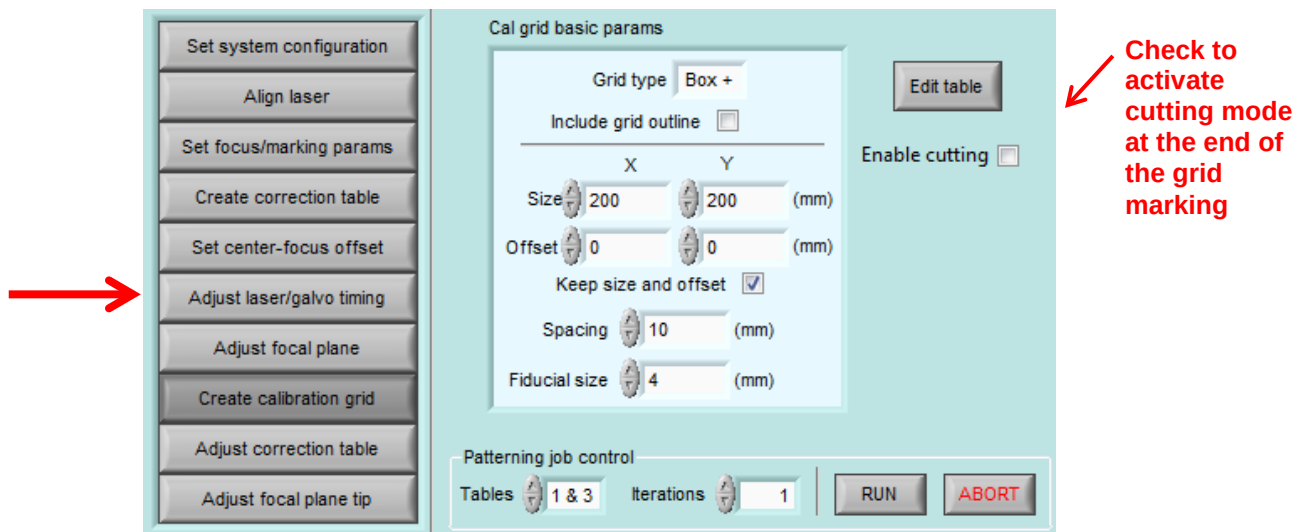


Figure 75: Create calibration grid View

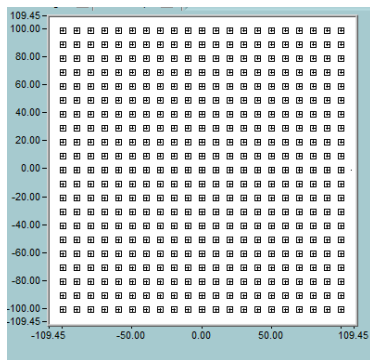
As mentioned in the introduction, the calibration process is made of three distinct parts:

1. Generation of a Calibration Grid Artifact
2. Measurement of Ideal vs. Actual coordinates
3. Analysis of measurement data & generation of a correction table

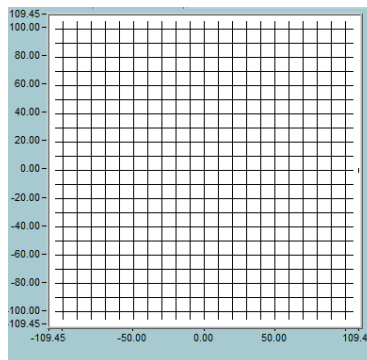
Generation of a Calibration Grid Artifact

Adjusting the correction table requires comparison of a known pattern's coordinates with measurements of actual coordinates on a marked piece. The **Create calibration grid** menu provides parameters to define a grid pattern.

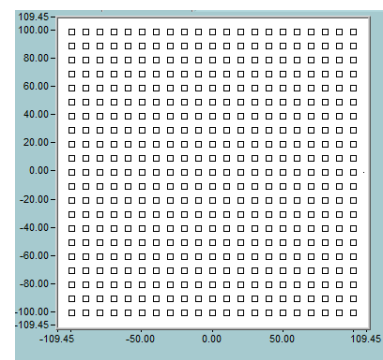
Five grid types are available:



Grid with Box and Cross

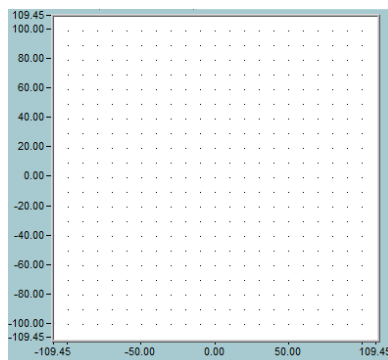


Grid with Lines

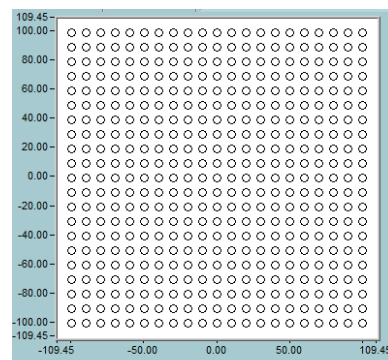


Grid with Box only

Figure 76: Calibration Grid Types



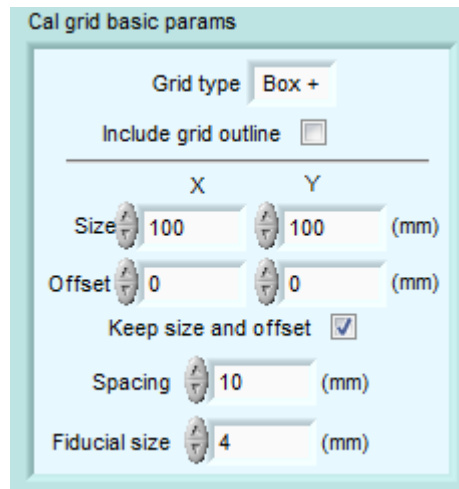
Grid with Dots



Grid with Circles

Figure 77: Calibration Grid Types (cont.)

1. The preferred type is the Line, as it results in clearly identifiable Fiducial (the junctions).
2. The parameters in this view allow you to define the grid. For best accuracy, the grid size and position should be similar to the field area you intend to utilize. A grid is computed and presented in the editor's viewing area.



Cal grid basic params

Grid type: Box +

Include grid outline: ☐

X Y

Size: 100 100 (mm)

Offset: 0 0 (mm)

Keep size and offset: ☒

Spacing: 10 (mm)

Fiducial size: 4 (mm)

Figure 78: Calibration Grid Parameters

3. The software will attempt to utilize the full field size available, modifying the grid based on the Size, Offset, Spacing and Fiducial Size values. The software might display windows that inform you on required changes, as a Fiducial must always be positioned at the center of the field.
4. Check the "Include grid outline" box if you wish to mark the field's perimeter using the galvo's maximum command values. Additional registration marks are drawn in the corners of the outline and at the X and Y positive maximum extents. These marks are useful for proper orientation on measurement tools. Note that even without the outline, a dot is marked just outside the grid to identify the positive-X direction.

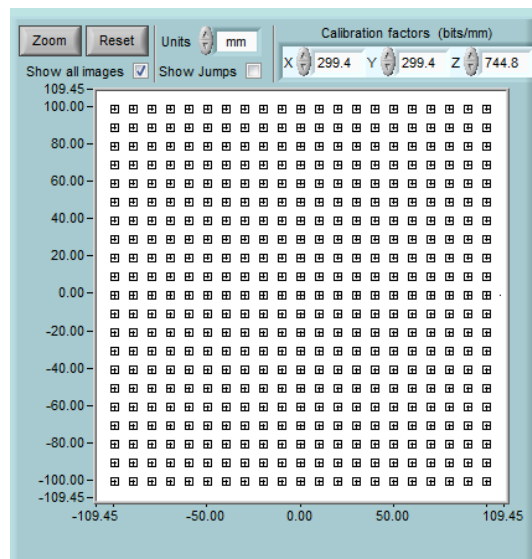


Figure 79: Calibration Grid Display

5. If grid elements at the edges of the field are incomplete or missing due to the initial distortion, start with a smaller field size and adjust for the full field after achieving a square field.

6. In some situations, it is convenient to cut the media on which the pattern is marked for the measurement step. If your laser is powerful enough, you can do this using the **Enable cutting** feature of CalWizard.
7. Check the box and define the cut dimensions. Note that a notch is cut at the positive-X direction for easy orientation.

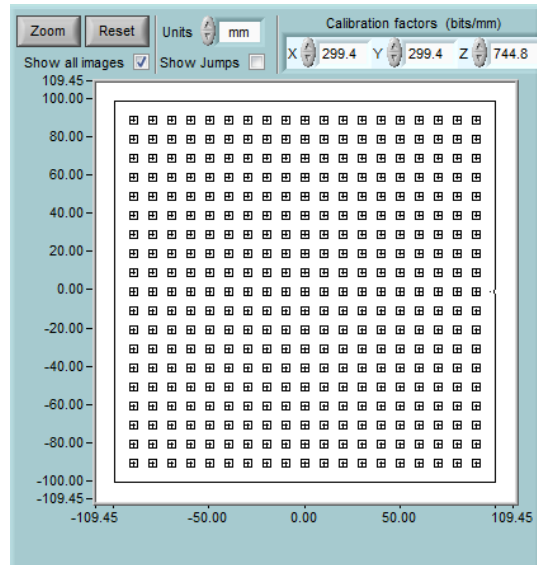


Figure 80: Check the Box and Define the Cut Dimensions



8. When you are done setting the grid pattern, click the Run button to mark it on the target.

Note: Using Bindakote or Chromalux black paper results in good contrast for most laser types.

Measurement of Ideal vs. Actual Coordinates

As mentioned in the introduction, the Calibration Wizard supports the following methods for acquiring the measured coordinates:

- Automatic analysis of a scanned grid image from a flat-bed scanner (limited to 300mm x 300mm field)
- Analysis of a grid measurement file provided by the user
- Manual-guided grid adjustments (useful for fields larger than 300mm x 300mm)
- Basic Box/Cross corrections (quick method for initial or “good-enough” accuracy)

Each of the above methods differs in its required effort and achievable accuracy. Please refer to “Calibration Methods” on page 61 to select the method that best suits your needs.

Analysis of a Grid Measurement File

Correction tables are created based on the analysis of the ideal vs. measured coordinate sets. This analysis is done by the software but requires different actions depending on the method you chose:

- If you use the automated measurement method or Guided Grid Measurement tool, the analysis will be done automatically as part of the process.
- For the Basic Box correction method, measurement is done through observation and no data is entered.
- Otherwise, mark the grid pattern (or a pattern of your choice) and use your own method to measure the coordinates of the marked pattern points. Then, create an ASCII text file listing ideal and measured coordinates side by side. Alternately, you can list the ideal coordinate together with the position error of the corresponding measured coordinates.

Both Point-set (pset) formats use multiple lines of text in a file, each line representing a separately measured grid point expressed in standard units of measurement (mm or inch). In each line, values can be separated by Spaces, Tabs, or commas.

1. Once the file is ready, go back to the correction table editor and select **File | Import | Measurement data from... | CTI point-set format file**, then choose the format of the table you have for import.

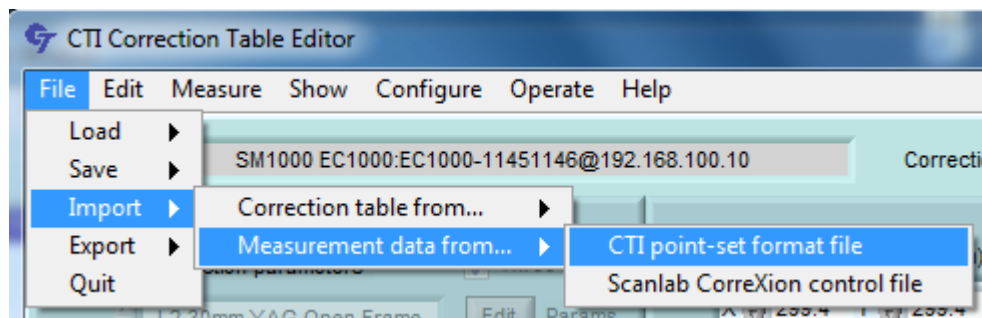


Figure 81: File | Import | Measurement data from... | CTI point-set format file

2. Click Import for the format (.pset or .dat) of the table you have for import.

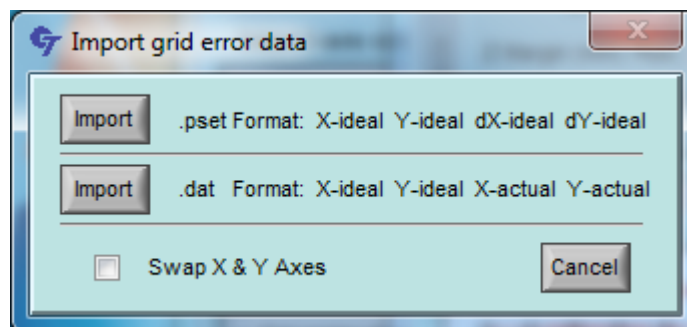


Figure 82: Import grid error data

3. Below are examples for the two data formats, one using the Tab separator and the other the semicolon separator.→

.dat Format (tab separator)				.pset Format (semicolon→ separator)			
X-Ideal	Y-Ideal	X-Actual	Y-Actual	X-Ideal	Y-Ideal	X-Delta*	Y-Delta*
-128.0→	-128.0→	-127.6778→	-128.011	-30.000000;	-30.000000;	0.298739;	-0.583034
-128.0→	-102.4→	-127.8725→	-102.5328	-25.000000;	-30.000000;	0.325006;	-0.518194
-128.0→	-76.8→	-127.9894→	-76.9497	-20.000000;	-30.000000;	0.358461;	-0.454425
-128.0→	-51.2→	-128.0576→	-51.3114	-15.000000;	-30.000000;	0.383666;	-0.390759
-128.0→	-25.6→	-128.0836→	-25.6478	-10.000000;	-30.000000;	0.423006;	-0.311030
-128.0→	0.0→	-128.0820→	0.0108	-5.000000;	-30.000000;	0.423832;	-0.222179
-128.0	25.6→	-128.0528→	25.6455	0.000000;	-30.000000;	0.457070;	-0.151964
-128.0→	51.2→	-127.9810→	51.2527	5.000000;	-30.000000;	0.492804;	-0.087841
-128.0→	76.8→	-127.8751→	76.8149	10.000000;	-30.000000;	0.529238;	-0.016025
-128.0→	102.4→	-127.7240→	102.3285	15.000000;	-30.000000;	0.535826;	0.059729
-128.0→	128.0→	-127.4911→	127.7597	20.000000;	-30.000000;	0.531174;	0.149579
-102.4→	-128.0→	-102.2990→	-127.8040	25.000000;	-30.000000;	0.563012;	0.227755
-102.4→	-102.4→	-102.4243→	-102.3363	30.000000;	-30.000000;	0.623177;	0.302295
-102.4→	-76.8→	-102.5034→	-76.7753	30.000000;	-25.000000;	0.521047;	0.373780
-102.4→	-51.2→	-102.5497→	-51.1900	25.000000;	-25.000000;	0.466701;	0.300140
...				...			

* $X\text{-Delta} = X\text{-Actual} - X\text{-Ideal}$; $Y\text{-Delta} = Y\text{-Actual} - Y\text{-Ideal}$

Figure 83: User Measurement File Samples

4. Regardless of the method used to calculate the correction table, the editor DOES NOT includes rotation and offset corrections in the table data.
5. Measurement data statistics represent the errors in the actual raw data with offset and rotation removed. Model accuracy statistics represent how well the mathematical models are predicting the actual measurements (i.e., the difference between the actual measurements and the modeled measurements at each location). Min and Max represent the worst-case errors in the field; Mean is the average error, and SDev is the standard deviation.
6. Save the adjusted correction table before you quit the editor.

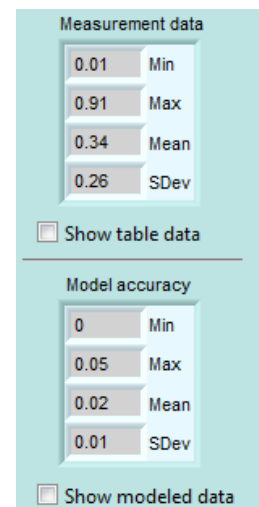


Figure 84: Measurement Data and Model Accuracy

To return to the procedure overview for 2-axis heads, click on [2-Axis Head Procedure Overview](#).

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Adjust Correction Table

In some situations, an existing correction table requires a global adjustment for scaling or trapezoid to address system-to-system variations or mechanical misalignments. This can also be an easy calibration method if your system does not require the utmost accuracy. Both adjustment and coarse calibration can be achieved through the **Adjust correction table** menu.

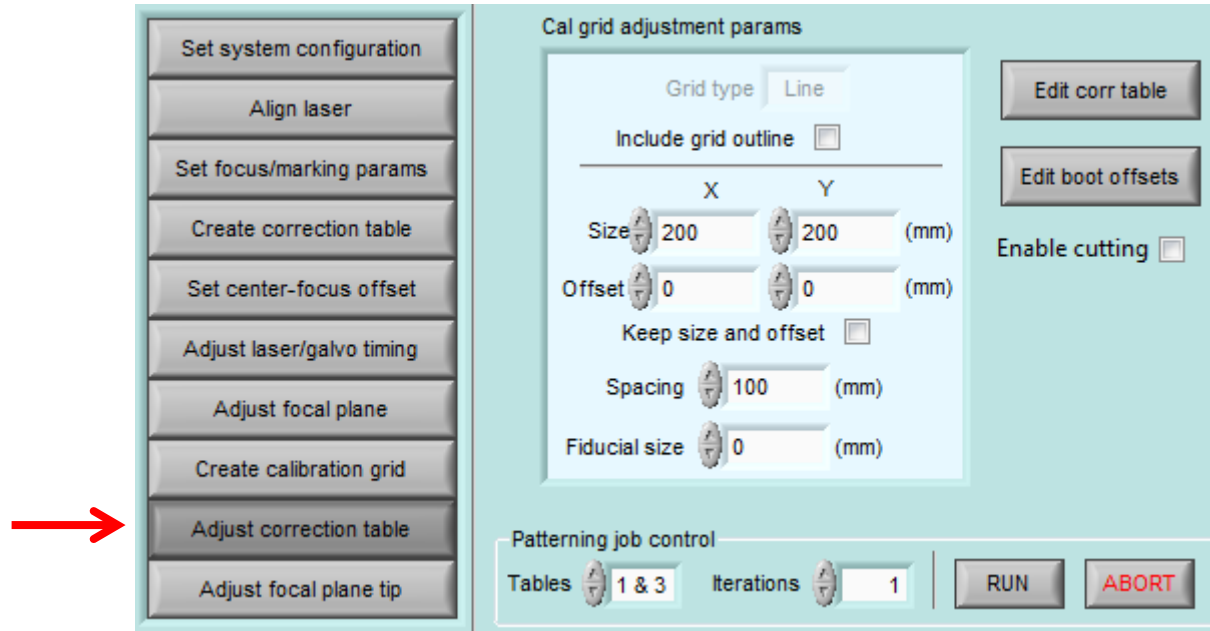


Figure 85: Adjust correction table view

1. Use the controls in Task parameters to define a simple box & cross design in the graphic display.

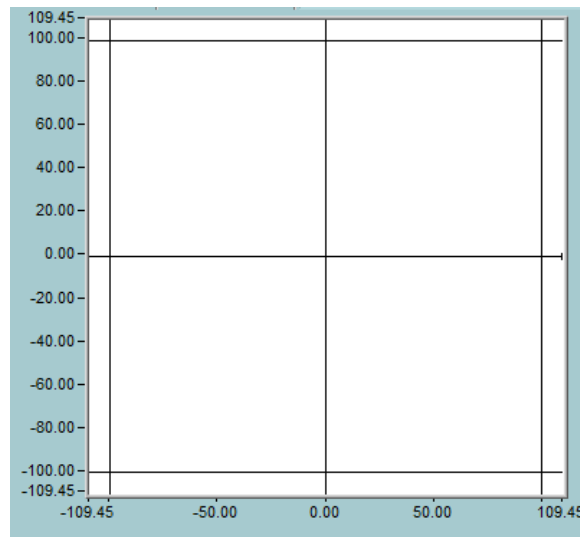


Figure 86: Box & Cross Pattern



Your Next Action Will Fire The Laser!
Use Caution To Avoid Damage Or Injury!



2. When you are done setting the grid pattern, click the Run button to mark it on the target.

3. Once the pattern is marked, click on the “Edit corr table” button to open the Correction Table Editor. Then select the **Measure | Collect Box/Cross grid data** menu option.

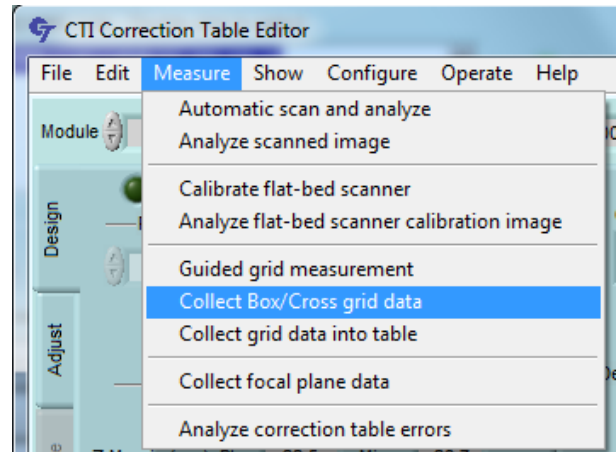


Figure 87: Measure | Collect Box/Cross grid data

4. Now, measure relevant dimensions on the marked pattern and enter them into the relevant locations in the presented diagram.

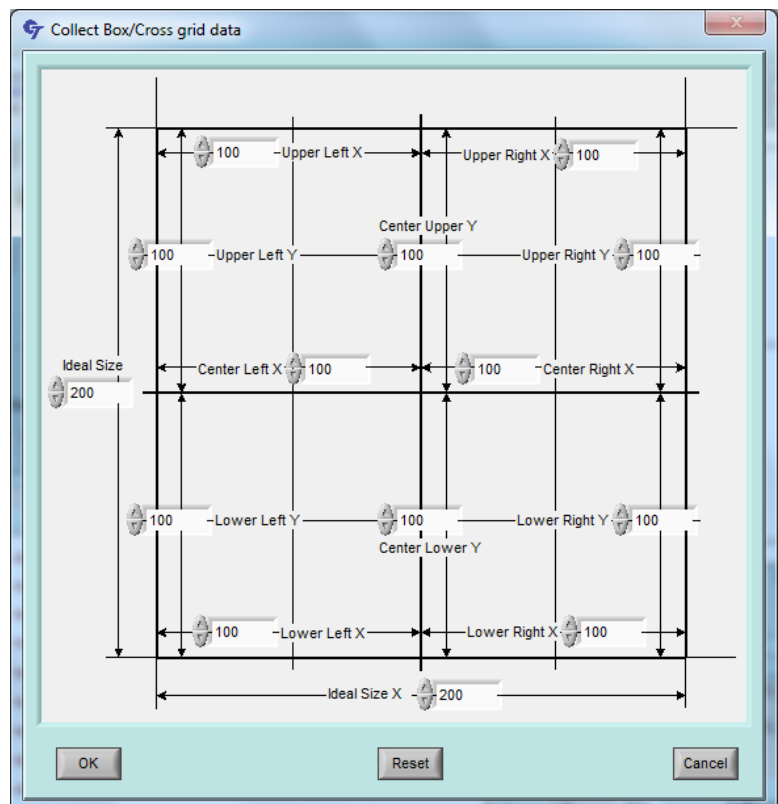


Figure 88: Box & Cross Data Entry Window

Note: Do NOT change the Ideal X and Y values!

5. Before quitting the editor, save the correction table by clicking OK in the Box & Cross Data Entry Window.
6. You will be prompted to save the measurement data. Click OK in this dialog box.

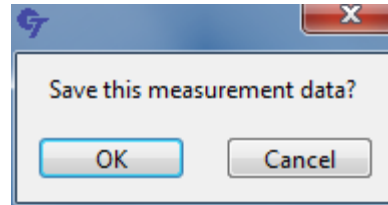


Figure 89: Save this measurement data

7. Select an existing **.pset** file, or enter a new one in which to save the measurement data. Then click OK in this dialog box.

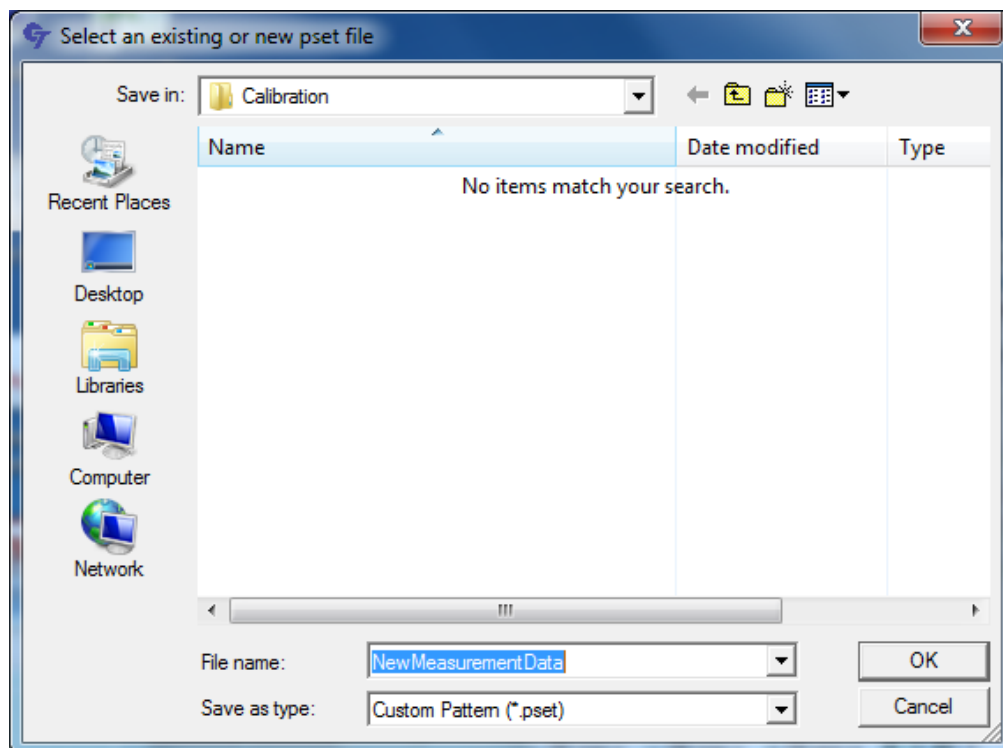


Figure 90: Select an existing or new pset file

8. If the whole pattern needs to be offset, click the Edit boot offset button in the CTI Calibration Wizard to display the following dialog box. Edit the boot offsets in the following dialog box and click the OK button.

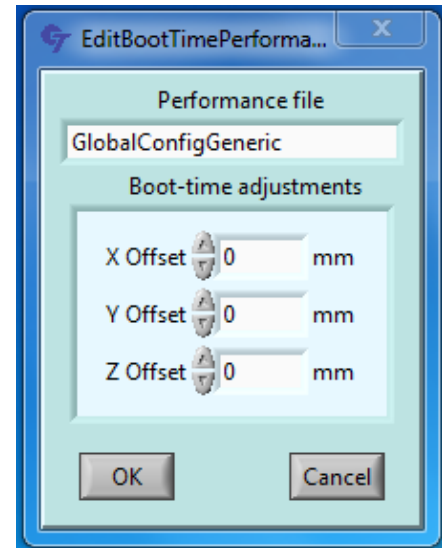


Figure 91: Boot Offsets

9. The Boot Offsets dialog box will be redisplayed, showing the actual boot offsets. Click the OK button to accept these offsets.

To return to the procedure overview for 2-axis heads, click on [2-Axis Head Procedure Overview](#).

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Adjust Focal Plane Tip – 3-Axis Heads

The final step for a 3-Axis head is fine adjustment of the focal plane (if needed).

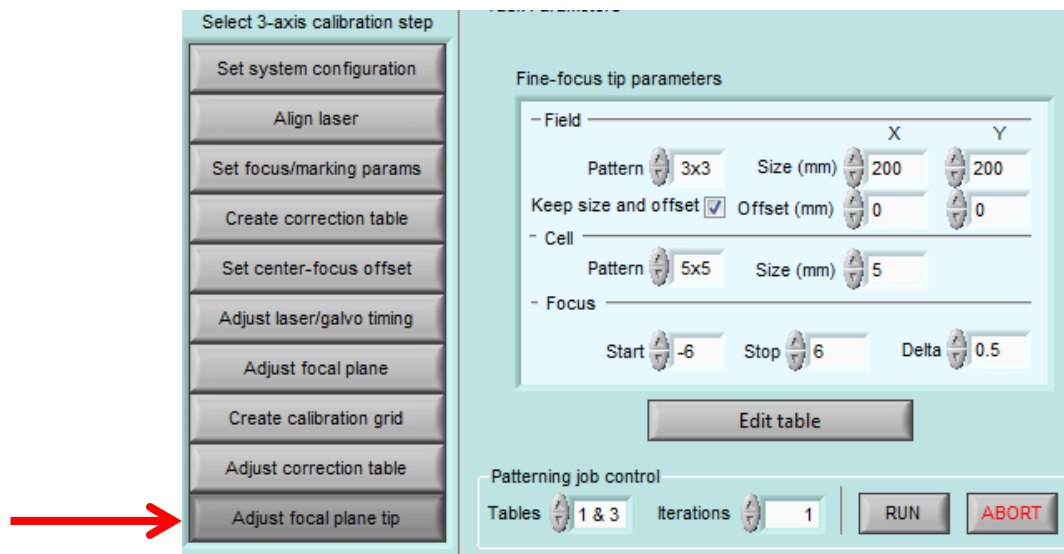


Figure 92: Adjust focal plane tip view

The same Focusing Array pattern is used as for the initial focal plane adjustment.

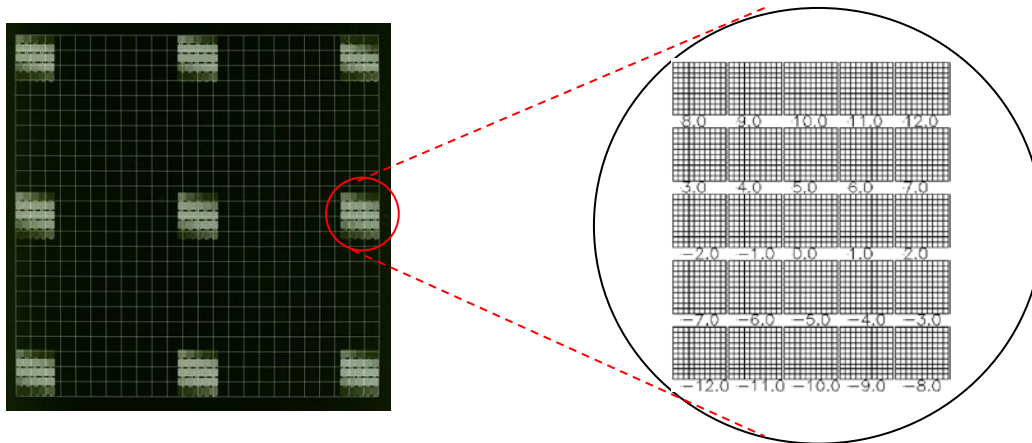


Figure 93: Adjust focal plane Pattern



**Your Next Action Will Fire The Laser!
Use Caution To Avoid Damage Or Injury!**



1. Set the grid pattern, and then click the Run button to mark it.
2. Once the pattern is marked, click on the “Edit table” button to open the Correction Table Editor
3. If you get the following message dialog, click the OK button.

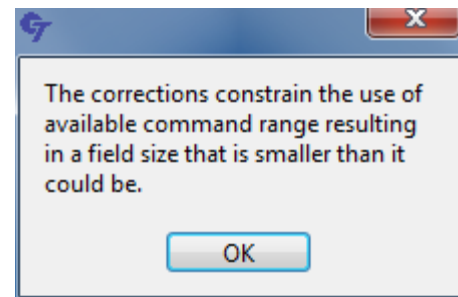


Figure 94: Corrections Constraints Message

4. The following message dialog may be displayed. If you want to enable Auto-scaling, click the OK button; if you do *not* want to enable Auto-scaling, click the No button. (For more information on Auto-scaling, refer to “Table Auto-Scaling” on page 76.)

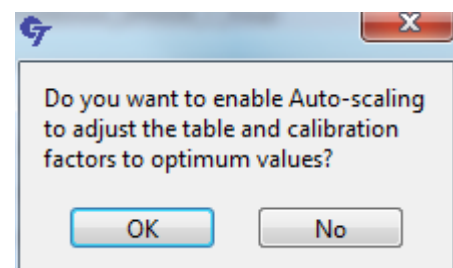


Figure 95: Auto-scaling Message

5. If the following message is displayed, take note of it and click the OK button.

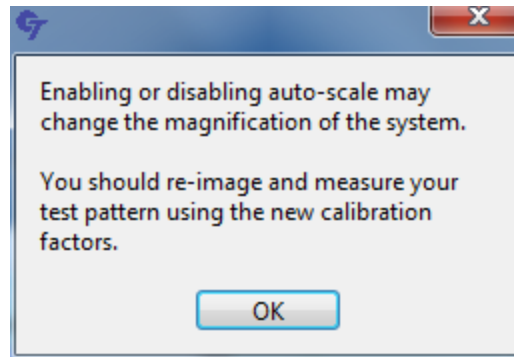


Figure 96: Auto-scaling Magnification Message

6. Select the **Measure | Collect focal plane data** menu option from the Correction Table Editor.

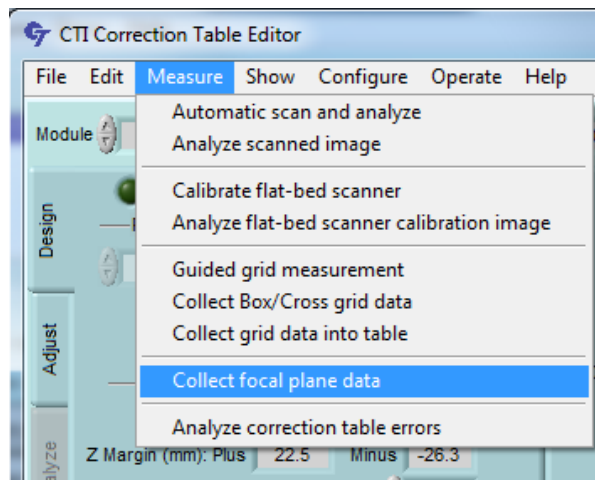


Figure 97: Measure | Collect focal plane data

7. Discern the best offset to get a focused beam in each location and enter them into the corresponding field in the following screen to enable the software to compensate for non-flatness across the marking field.

Figure 98: Focal Plane Tip Data Entry Window

Note: the information entered through this tool is accumulative; while the presented values are reset to zero every time you open the tool, previously applied corrections remain in effect.

To return to the procedure overview for 3-axis heads, click on [3-Axis Head Procedure Overview](#).

Calibration Methods

This chapter discusses the various calibration methods supported by the Calibration Wizard.

Automatic Measurement and Analysis

The preferred method to acquire measured coordinates is the automatic analysis of a scanned image. This correction method is suitable for calibrating scan fields up to 300mm x 300mm. In this method, Cambridge Technology's patent-pending Scanner Based Metrology uses standard document scanning equipment coupled with advanced vision processing algorithms to create a good correction table with one or two passes of imaging, measurement, and analysis. This system electronically captures a large array of fiducial images (produced by a laser system on a substrate) into a TIFF pixel-based image file. The image file is then methodically analyzed in sub-regions, using vision processing software at each "ideal" fiducial location to produce an X-Y offset of the fiducial relative to the "ideal" position. These offsets are measured in pixel units but are easily converted into English or Metric units based on the scanning resolution of the equipment being used.

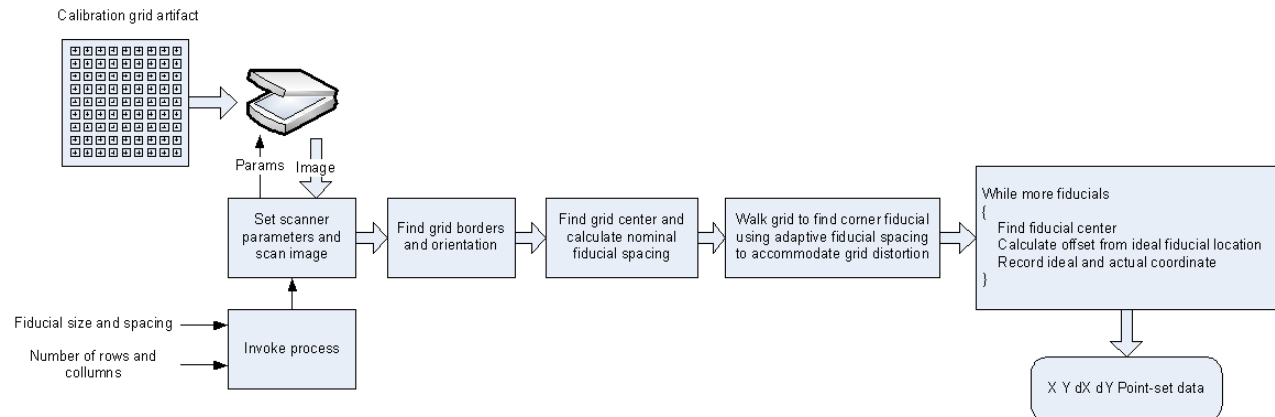


Figure 99: Scanner-Based Metrology Data Flow

The advantage of such a system is that it uses readily available low-cost digital image scanning equipment as a metrology tool instead of low-accuracy and error-prone human measurement, or high-accuracy and expensive metrology equipment that uses linear X-Y stages coupled with optical microscopes, image capture, and vision processing software.

Today's document scanning equipment is fabricated using high-precision semiconductor process equipment and large-area lithography methods that ensure good dimensional tolerances. For applications that require the utmost accuracy, the flat-bed document scanner's inaccuracies can be characterized and eliminated from the measurements. See "Appendix A: Flat Bed Scanner Characterization" on page 69 for more information.

If the above measurement method is not initiated immediately following marking the grid, make sure to reload whatever correction file was used for the marking and to redefine the grid the same way it was for the marking.

To ensure the best results, load the flatbed scanner calibration file before starting as described in “Appendix A: Flat Bed Scanner Characterization” on page 69.

Note: Calibration Wizard currently supports two types of Flatbed Scanners: [1] [Canon Canoscan Lide 700F](#) and [2] [Plustek OpticPro A320](#). In addition, the Calibration Wizard is based on LabView libraries and the user will need to purchase a [NI Vision Development Module Run-Time License](#) from National Instruments. Use National Instrument’s Software Vision860 and not a newer version. You can contact CTI to get this software product.

The following is a step-by-step procedure for the Automatic scan and analyze method:

1. After the grid is patterned on a suitable substrate (the “artifact”), place it in the document scanner so that scanning start at the positive-Y edge and progresses along the Y axis. Then, click the “Edit table” button to open the Correction Table Editor. From the editor’s menu, select **Measure | Automatic scan and analyze**.

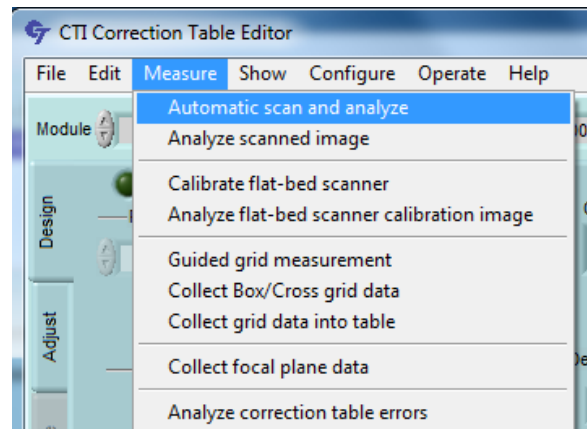


Figure 100: Automatic Scan & Analyze Menu Option

2. Enter the file name you want to use. This will serve as a prefix to various files the software will create during the operation.

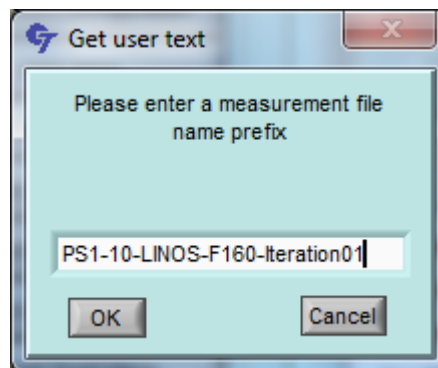


Figure 101: Get user data

3. Browse to the folder where you want the software to save image files. Type in a sub-folder name and click “Save” to create a new sub-folder, or click “Current folder” to save the file into the selected one.

4. Select the Scanner size and define the orientation of the scanned image on the flat-bed document scanner.

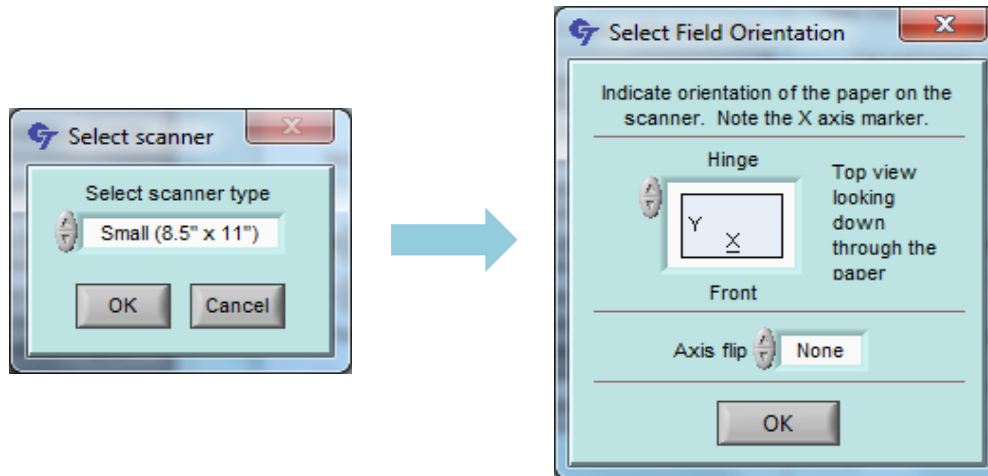


Figure 102: Select Scanner Type and Field Orientation

5. Select the scanner you'll be using from the list of installed scanners.

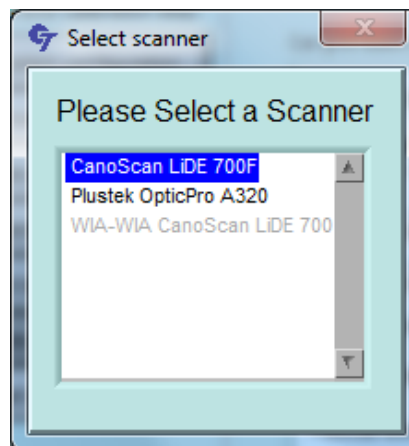


Figure 103: Select the Scanner

6. An activity bar will be displayed while the scanner processes the item. The image is scanned twice—first as a low-resolution image of the item and next as the full resolution image.

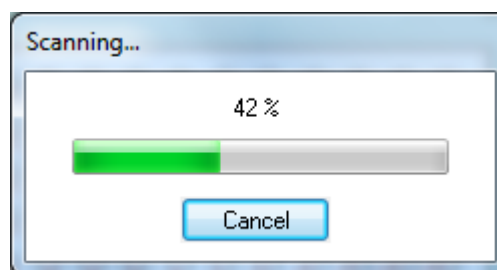


Figure 104: Scanning Status Window

7. At the end of the scan, the scanned image is saved to the folder you have previously selected and can be used for repeating the analysis without the original artifact.

8. Now the software will start the analysis by opening the image file.

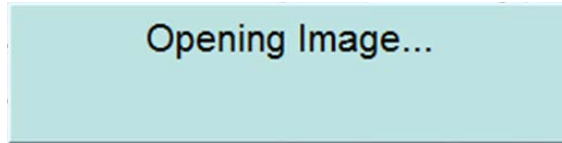


Figure 105: Opening the Image File

9. A small window will display the sub-region of the image being analyzed, including highlights of identified features, while a progress message will show progress status.

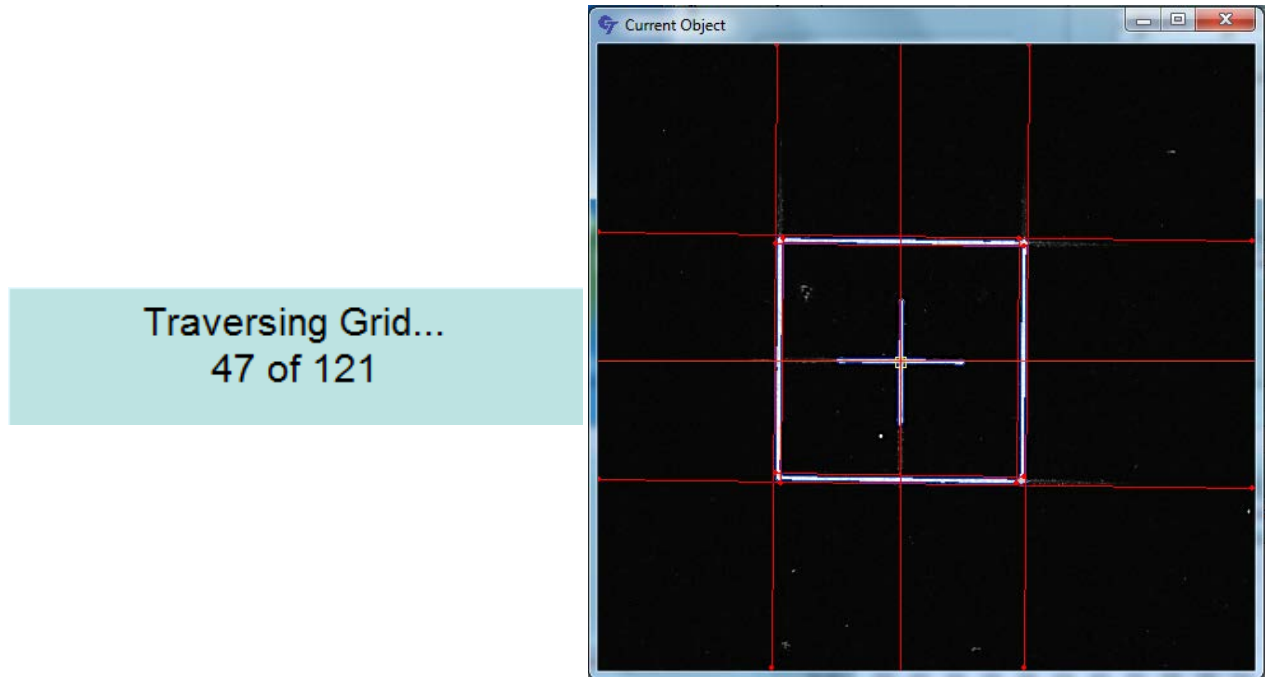


Figure 106: Traversing Grid...

10. At this point, a "pset" file is created from the scanned image and is saved to the folder you have previously selected.
11. Once a set of measured coordinates is available for each of the design points, the differences are analyzed using least-squares regression techniques to develop coefficients for mathematical models of the system errors.
12. In addition, Calibration factors are calculated automatically based on the deviation of the measured overall dimension from the designed one. These values control how units are converted between user measurements (normally expressed in millimeters or inches) and system units of Galvo command counts.

- To complete the process, save the resulting correction information onto the controller or to a local file.

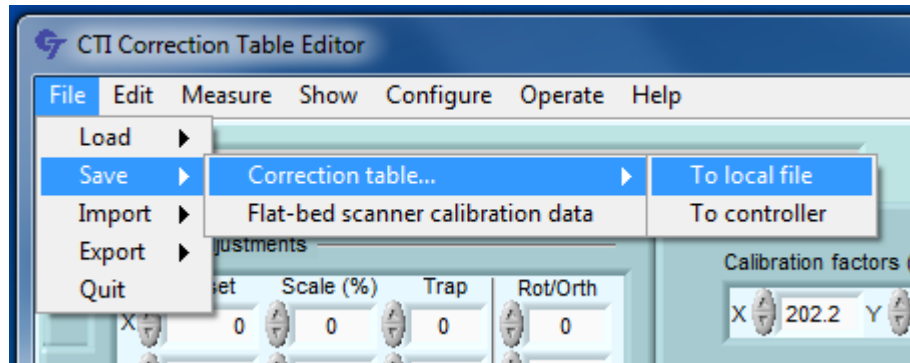


Figure 107: Save | Correction table... | To local file

Guided Grid Adjustments

This correction method is suitable for calibrating any scan field size, but is most useful for fields larger than 300mm x 300mm. The software is using the information in the current correction table to position a guide laser on the points of a user-defined grid. The user then uses on-screen controls to adjust the laser beam onto an accurate position (referring to a grid paper or other fiducials on the work surface). This method's accuracy is limited by the guide laser's spot size and the targets used. In addition, it can require more effort than the other calibration methods.

- To activate this feature, use the **Create correction table** menu and select the **Measure | Guided grid measurement** menu option.

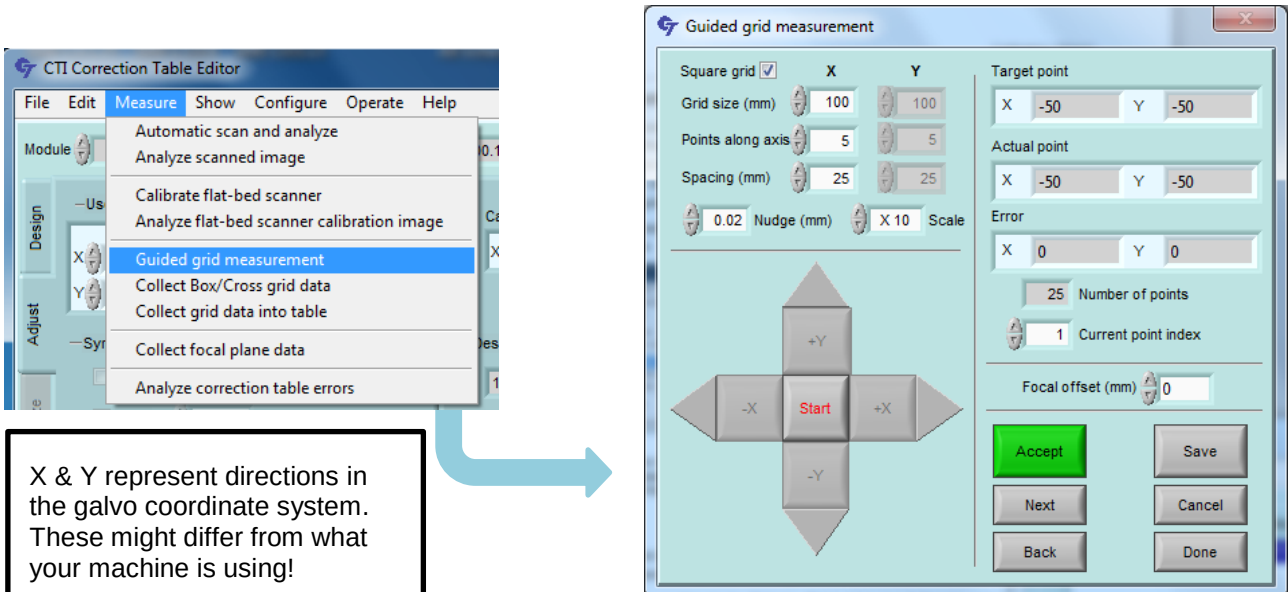


Figure 108: Guided Grid Measurement Window

- Use the Focal offset control to focus your guide laser on the target. This is required to compensate for the difference in wavelength from the main laser. This adjustment will NOT affect the Z offset value that was set previously.

3. Define the grid you want to use through the Grid size, Points along axis, & Spacing controls (note that they are inter-related). Define the “nudge” size and scale, and then click the “Start” button in the middle of the arrows.
4. The software will move the guide laser to the first point of the grid. Use the arrows to “nudge” it to the required position on the target. Change nudge size and scale as needed.
5. Once in position, click the “Accept” button to add this correction to the table in the computer’s memory and move the laser to the next point in the grid.
6. Use the “Next” and “Back” buttons to move between points on the grid without affecting the correction value in memory.
7. Use the “Save” button to save a copy of the updated table from the computer’s memory to a “pset” file. Refer to the next section for information about “pset” files and their use for generating a correction table.
8. Use the “Done” button to close the tool window and load the corrections into the Correction Table editor tool.

Note: You can use a 3x3-point grid for the first iteration to eliminate the bulk of the errors, so that the position accuracy of the software for subsequent iteration will be much improved.

Basic Box Correction

For 2-Axis applications that only require basic accuracy (‘it looks straight to me!’), a simple correction can be achieved by doing the following:

1. Follow the steps listed in “2-Axis Head Procedure Overview” on page 13, skipping “Create calibration grid”. The first time you mark the box & cross under the “Adjust correction table” menu, your box will most likely not look good due to mirror separation “pincushion” and lens “barrel” effects.

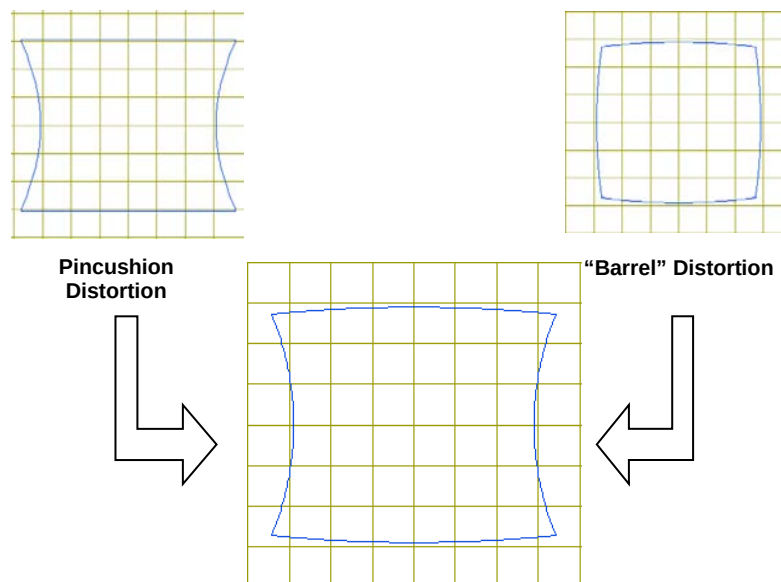


Figure 109: Pincushion & Barrel Distortions

- Click on the “Edit corr table” button to open the Correction Table editor and select the “Adjust” tab on the upper-left area of the window.

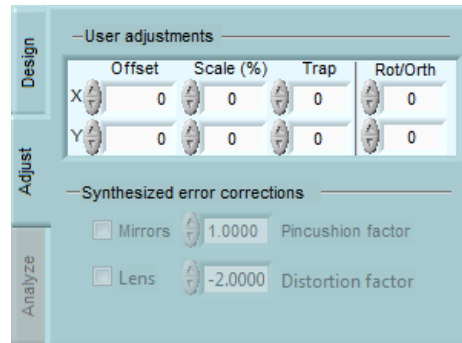


Figure 110: Adjust Tab

- Select the **Edit | Reset correction table** menu option to enable the Mirrors and Lens controls.

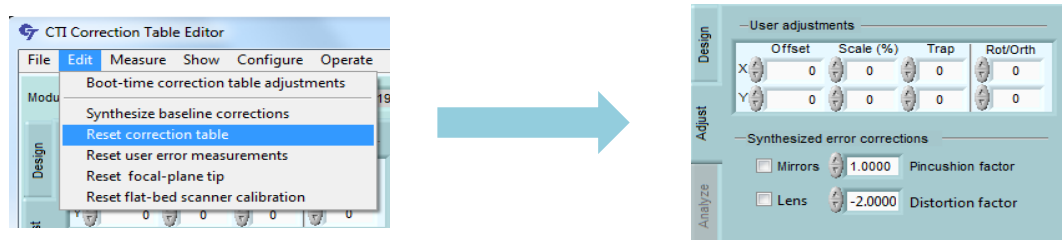


Figure 111: Edit | Reset correction table

- Start by switching on the “Lens” correction to introduce radial lens distortion compensation. Switching “Lens” correction on will also trigger a dialog box that queries you to enable auto-scaling of the table contents. Auto-scaling alters the table contents to ensure that all galvo commands that emerge from the run-time table computation are physically attainable. This is explained in more detail in “Table Auto-Scaling” on page 76.
- Adjust the lens correction factor then exit the editor, accepting the changes and loading the new table to the controller. Mark the pattern again and examine the top and bottom edges. Usually, larger factor values will push the corners away from the center of the field.
- Repeat this process until these two edges are straight (ignore the left and right edges for now).

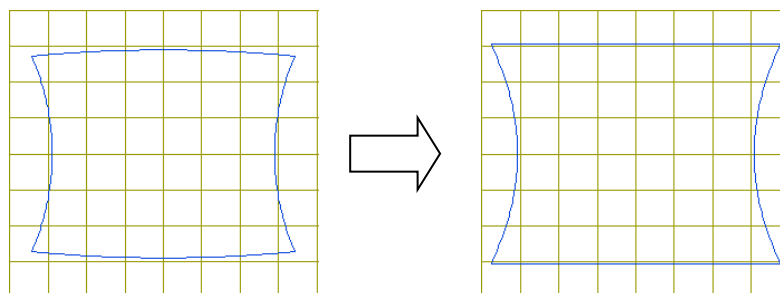


Figure 112: Lens Distortion Correction

7. Now switch on the “Mirrors” correction to introduce pincushion distortion compensation. The magnitude of the required pincushion correction depends on the maximum mirror angle and the lens effective focal length.
8. Adjust the lens correction factor then exit the editor accepting the changes and loading the new table to the controller. Mark the pattern again and examine the left and right edges. Usually, smaller factor values will pull the corners towards the center of the field.
9. Repeat this process until these two edges are straight.

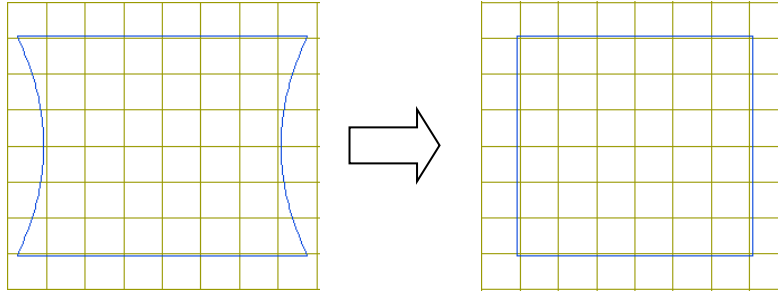


Figure 113: Mirrors Distortion Correction

The User adjustments controls allow you to induce additional compensations into the table. These factors are added to the lens and mirror compensations. These are normally not used except in special cases.

Appendix A: Flat Bed Scanner Characterization

Today's document scanning equipment is fabricated using high precision semiconductor process equipment and large area lithography methods that ensure good dimensional tolerances. For applications that require the utmost accuracy, the flat-bed document scanner's inaccuracies can be characterized and eliminated from the measurements using the following process:

1. Acquire a Characterization grid from Cambridge Technology and place it in the document scanner.
2. Click the "Edit table" button to open the Correction Table Editor. From the editor's menu, select **Measure | Calibrate flat-bed scanner**.

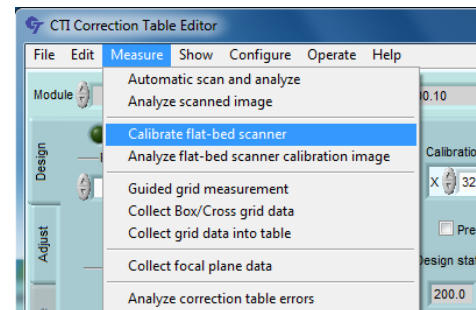


Figure 114: Flat-Bed Scanner Characterization

3. Select your scanner type and click the OK button.

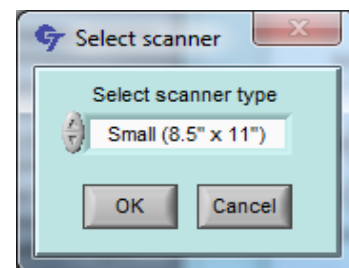


Figure 115: Select scanner type

4. Enter the file name you want to use. This will serve as a prefix to various files the software will create during the operation. Then click the OK button.

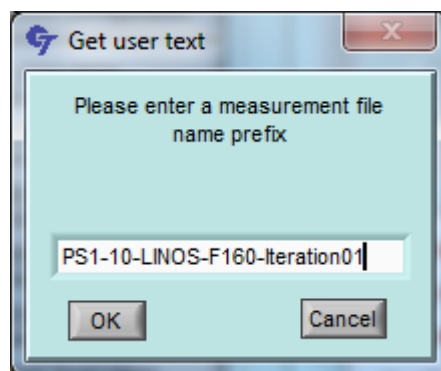


Figure 116: Get user text

5. Select a measurement data file and click the OK button.

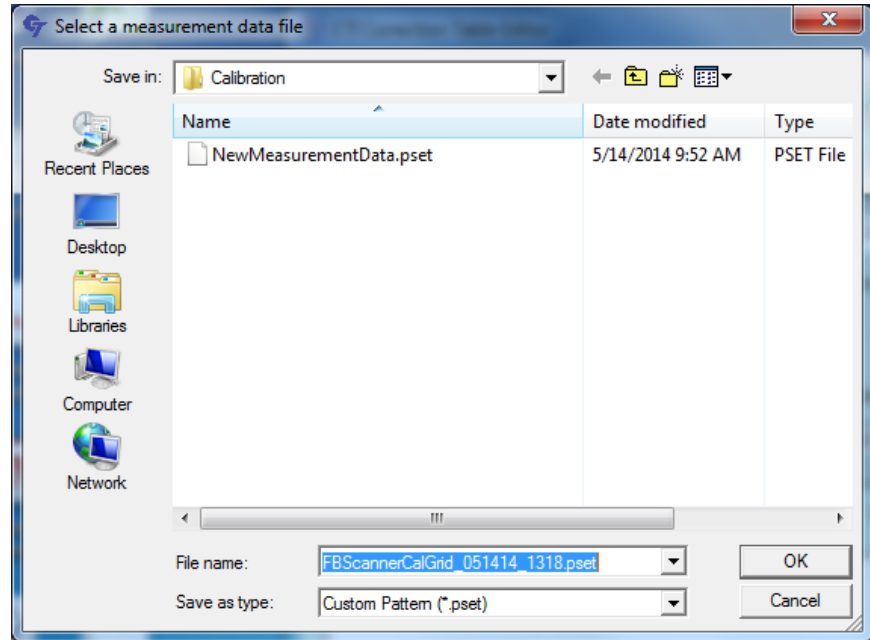


Figure 117: Select a measurement data file

6. Select the scanner you'll be using from the list of installed scanners.

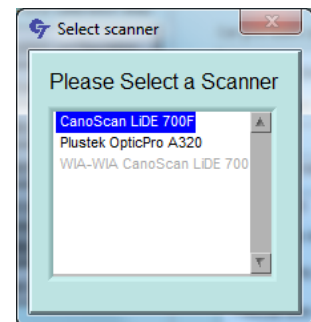


Figure 118: Select scanner

7. An activity bar will be displayed while the scanner processes the grid. (**Note:** The grid is processed twice—the first time as a low-resolution image and the second time as the full-resolution image.)

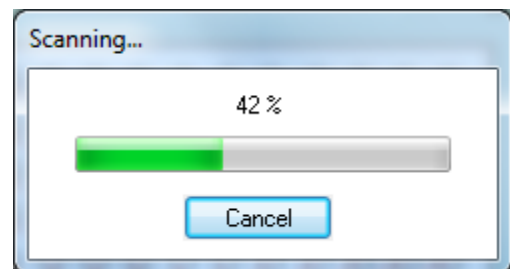


Figure 119: Select scanner

8. Now the software will start the analysis by opening the image file.

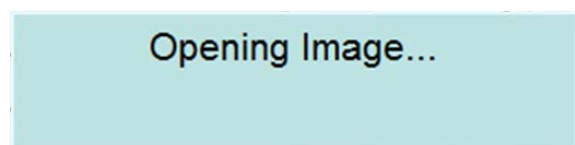


Figure 120: Select scanner

9. A small window will display the sub-region of the image being analyzed, including highlights of identified features, while a progress message will show progress status.

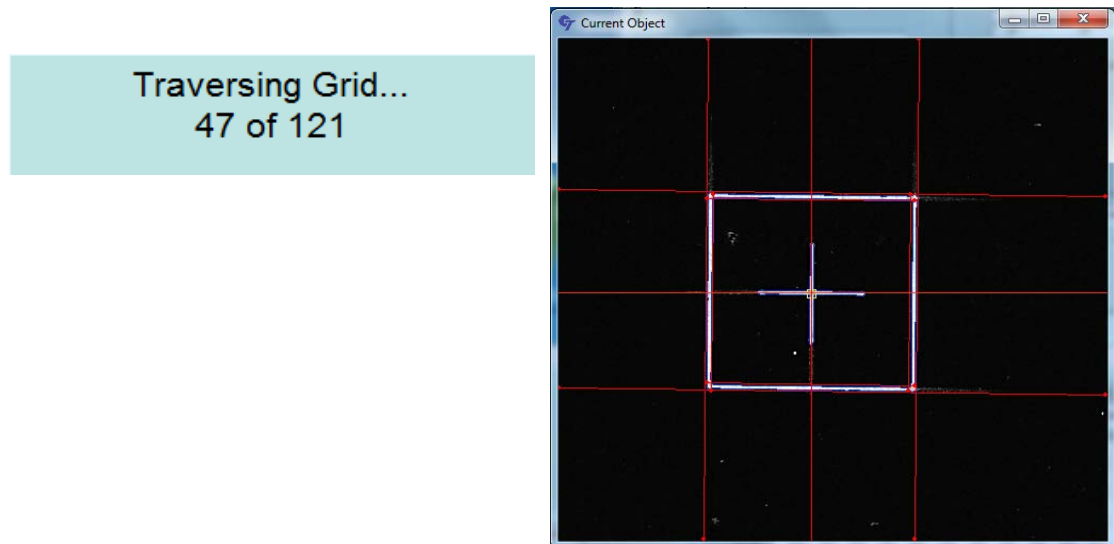


Figure 121: Traversing Grid...

Appendix B: Correction Table Editor – Graphic Display

Graphic Display Controls

The editor's graphic display provides the following controls.

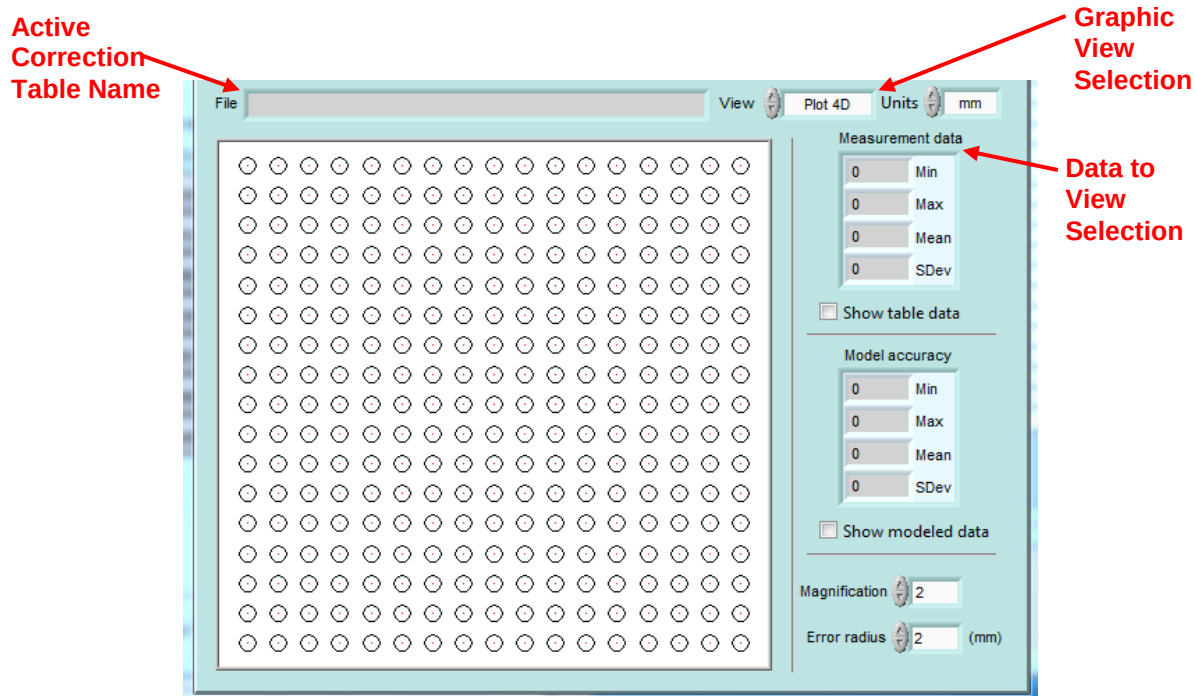


Figure 122: Correction Table Editor Graphic Display

Views Selection

The editor's graphic display shows a visualization of the the correction table's contents. The first two views are available for all configurations, and the other three are used for 3-Axis systems only:

XY Plot	▪ XY Plot	Ideal locations, "adjusted" locations, galvos command limits and lens field
✓ Plot 4D	▪ Plot 4D	Default view – Correction / distortion vectors for each grid location
Z Axis	▪ Z Axis	Correction values (as a 3D surface)
New tip	▪ New tip	Current Focal Plane corrections (as a 3D surface)
Total tip	▪ Total tip	Overall Focal Plane corrections (as a 3D surface)

For XY Plot and Plot 4D, a visualization of the entire correction table is not practical (the information density is too high) so a 17x17 grid of a sampled data subset is presented.

Data to View Selection

These selections are used to include/exclude various information types and will change based on the view.

Content Selection

The Show selector lets you switch between a representation of the actual distortion, and that of the corrections.

View Controls

These controls are used to change the properties of the display area and will change based on the view.

Plot 4D View

In Plot 4D view, circles are centered at the coordinates of the table entries, and vectors represent the magnitude and direction of the X-Y correction/distortion at each point of the grid.

For example, the mirror-induced pincushion distortion on the left, will result in the pattern on the right:

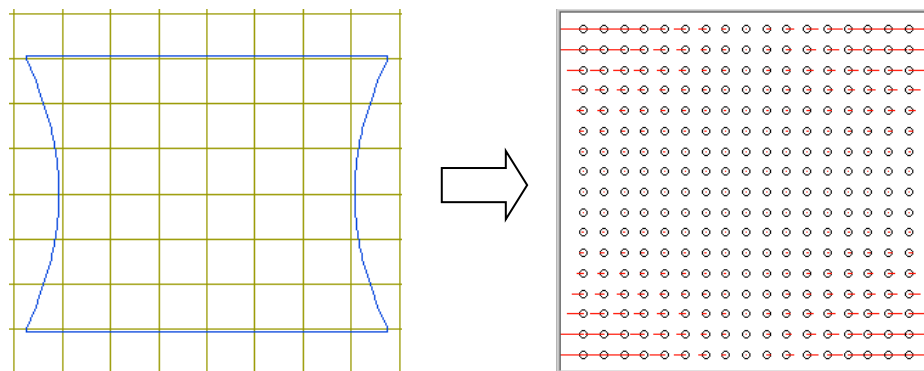


Figure 123: Mirror-induced Pincushion Distortion Visualization

Note that the red vectors emanating from the circles are always in the X direction and increase in magnitude as you move away from the $Y=0$ and $X=0$ axes. The vectors are pointing away from the center, indicating that for these points the actual mark will be “pushed” out compared to the intended location.

Changing the Content selection (Show) to Corrections, the vectors now point toward the center as they represent the corrections required to bring these points to their intended locations:

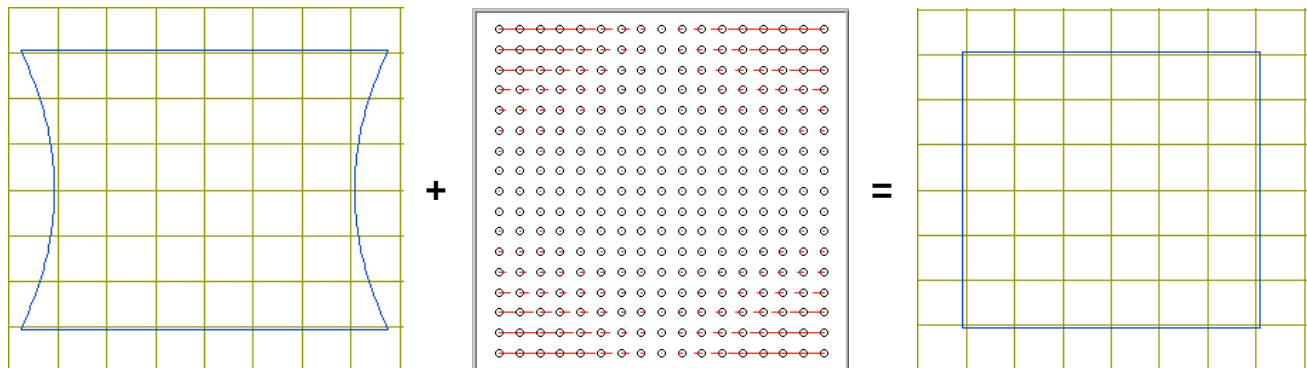


Figure 124: Mirrors' Pincushion Corrections Visualization

The radius of the circles and the magnification of the error vectors are controlled via the Radius and Zoom controls in the View controls section located at the bottom of the viewing area.

In the Data to View area, you can select what information is displayed. Table Data is displayed by default. You can also visualize patterns in imported measurement data and numerical analysis model predictions of that data.

At the bottom of the Data to View area is a statistics box that shows information about the data being viewed.

XY Plot View

An alternative view of the distortion/correction data is in X-Y Plot mode. To see the X-Y Plot, the user needs to turn on "Advanced Usage Mode". Remember, Advanced Usage Mode is only for the user who is using Calibration Wizard for advanced study of Distortion or correction. For general correction files, Advanced user Mode is not required.

To turn on Advanced Usage Mode, select **Configure | Advanced usage mode** from the menu bar of the Correction Table Editor.

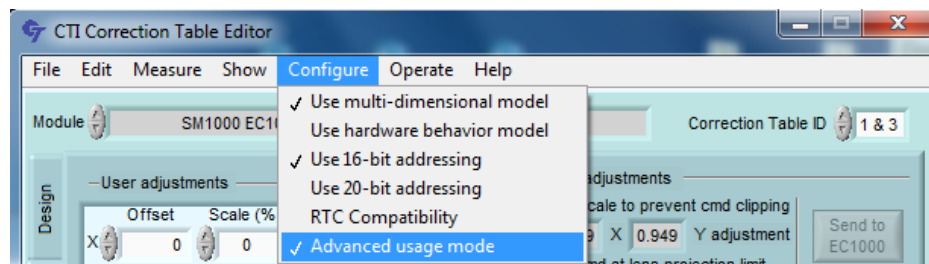


Figure 125: Configure | Advanced usage mode

The following is an example of the XY Plot View that displays in Advanced Usage Mode.

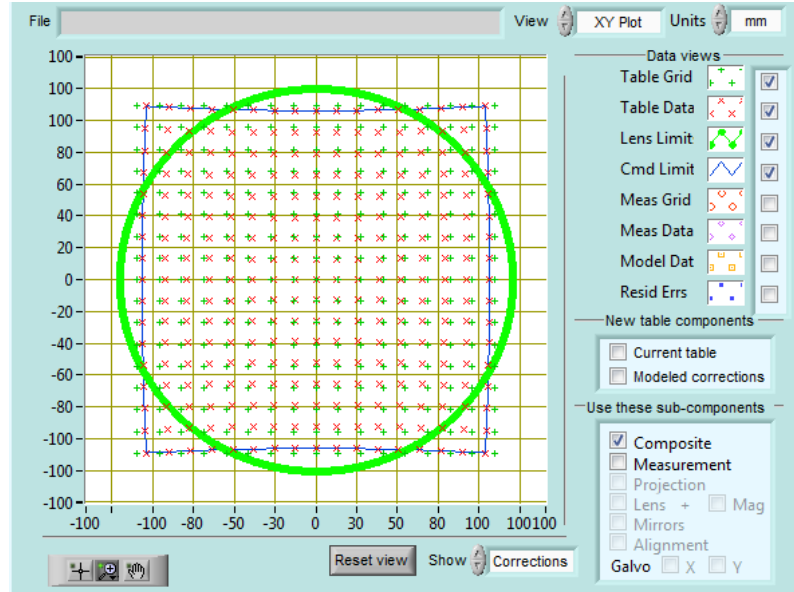
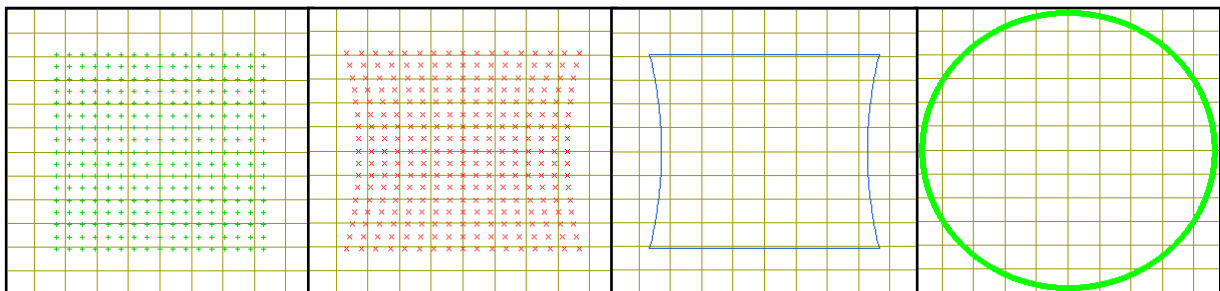


Figure 126: XY Plot View

The X-Y Plot View has different Data to View control elements than the Plot 4D one. In the default view (above), four data types are overlaid in the display.



Ideal locations of the table entry points (green "+" signs)

"Adjusted" locations of the table points (red "x" marks)

Maximum command position of the galvos (blue border)

Perimeter of the lens field (green circle)

Figure 127: Default Data Types in XY Plot View

Table Auto-Scaling

Unlike the pincushion distortion induced by the galvo mirror configuration, the Lens-induced distortions are radial: zero in the center of the field, and increasing in magnitude the further you move from the center in all directions. An uncorrected view of the distortions is shown below.

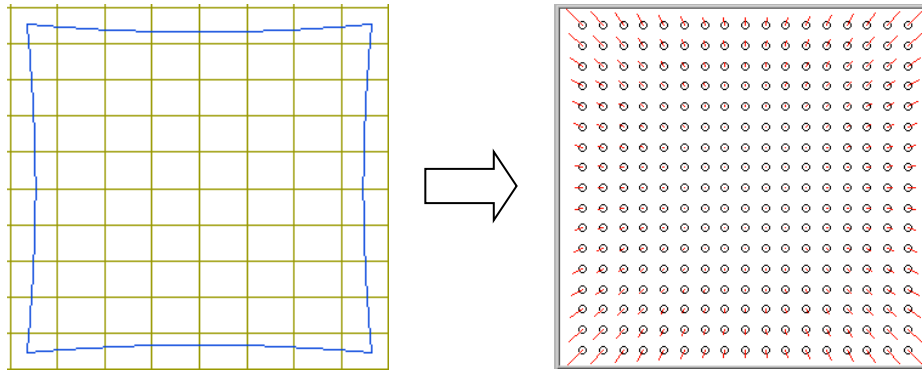


Figure 128: Lens' "Barrel" Distortion Visualization

As a result, correction values in the table might require galvo commands that exceed the ± 16 -bit range used by the controller. In the above illustration, the vectors at the perimeter of the table are pointing away from the circles at the edge of the view which represent the maximum command values the controller can generate.

Creating a table with such entries would result in command values bigger than what is possible in the system, hence clipping at the edge of the commanded field.

To avoid this situation, the editor will detect such circumstances and present the following warning, followed by a dialog box:

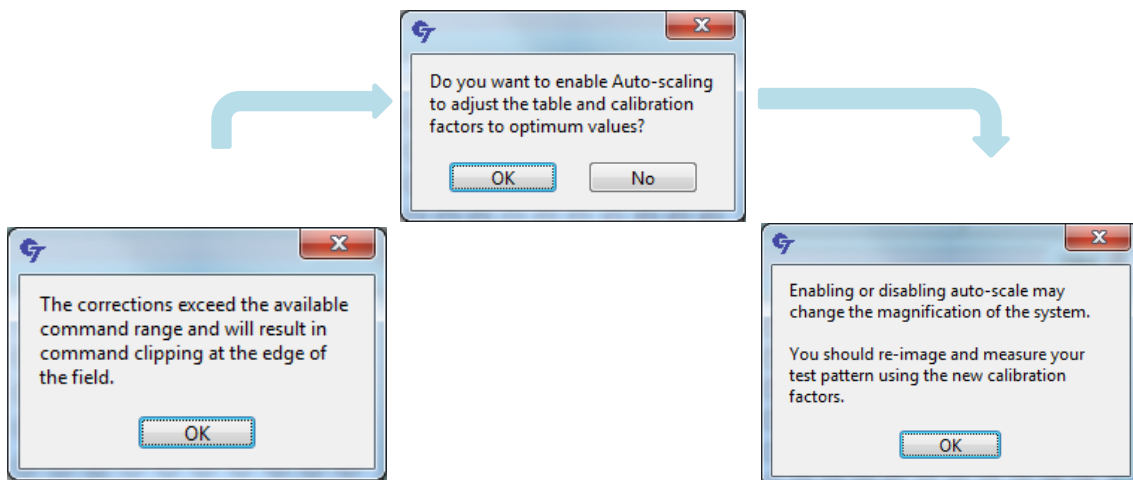


Figure 129: Auto-Scale Warning & Dialog Box

If you change the Auto-Scale setting, a dialog box will remind you that the adjusted value should be used.

Once enabled, auto-scaling will introduce an adjustment factor to "pull" the maximum command value to the limit of the controller's range.

Checking the Autoscale control box in the Overall adjustments area of the editor has the same effect as checking the Enable autoscale control in the preceding dialog box.

The display changes as shown below, to illustrate the effects of this scaling correction:

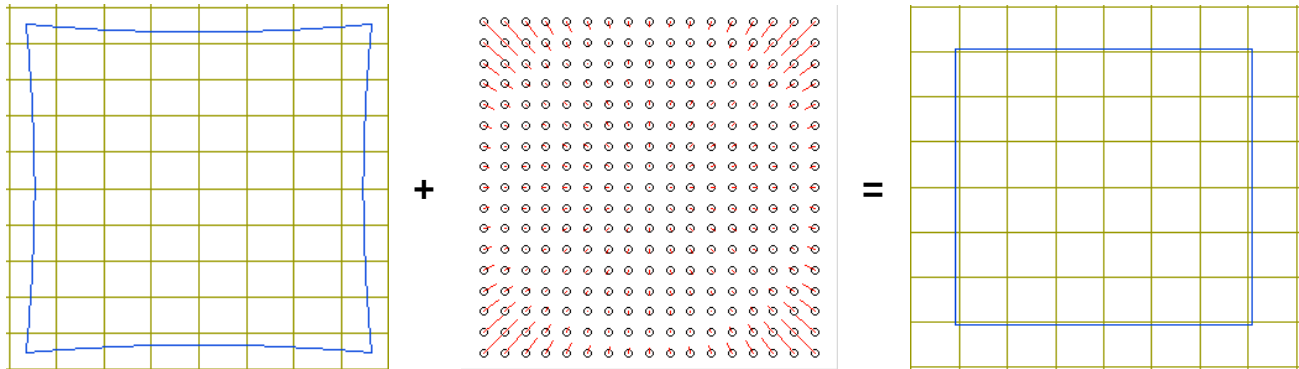


Figure 130: Lens' "Barrel" Corrections Visualization

The combined effect of galvo mirrors and lens distortions will result in the following correction table:

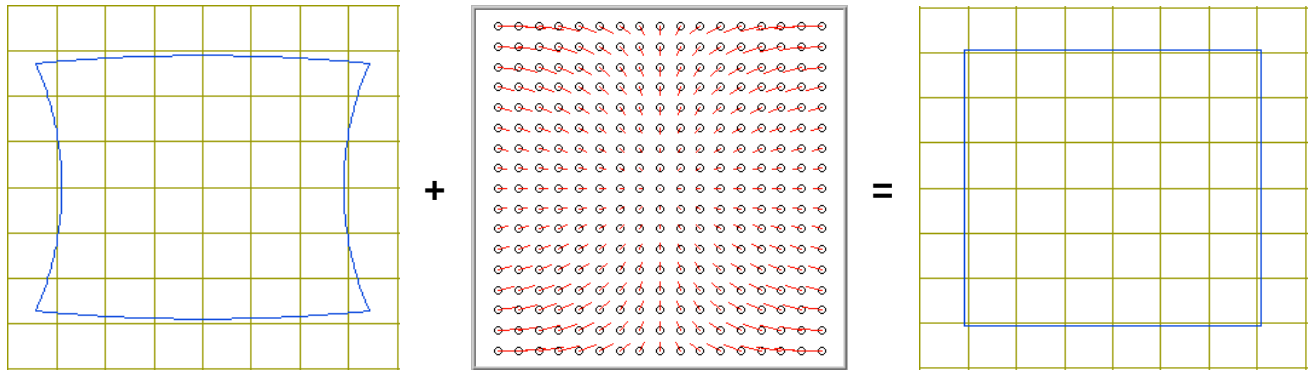
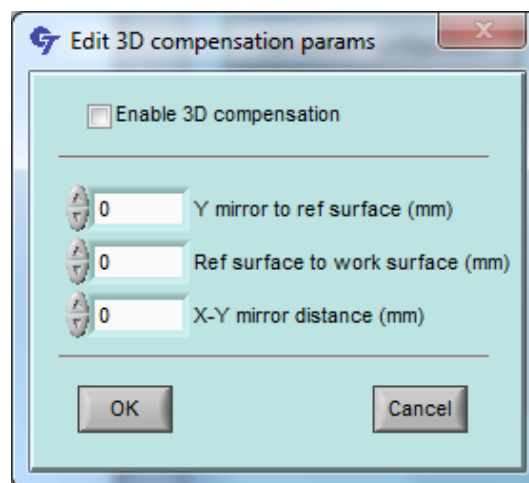
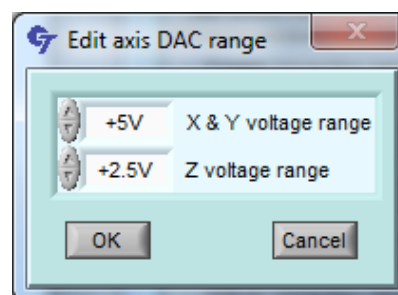
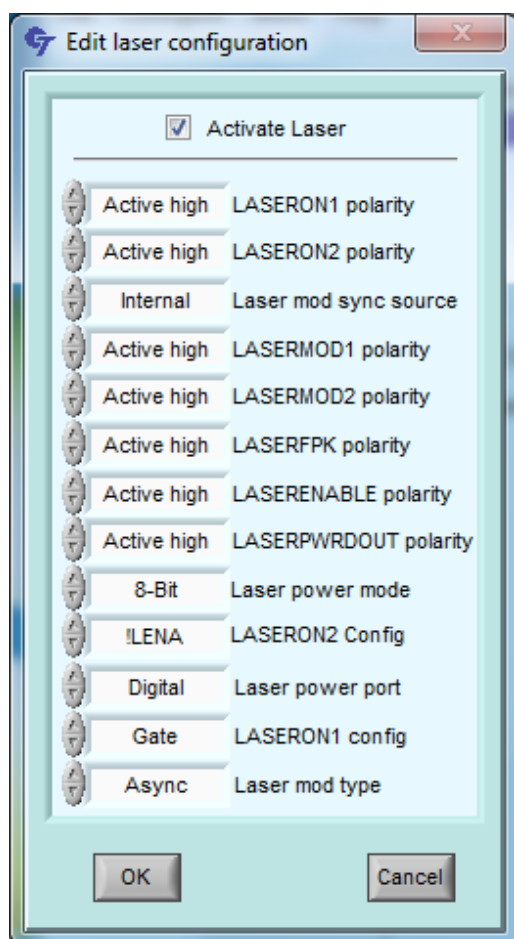
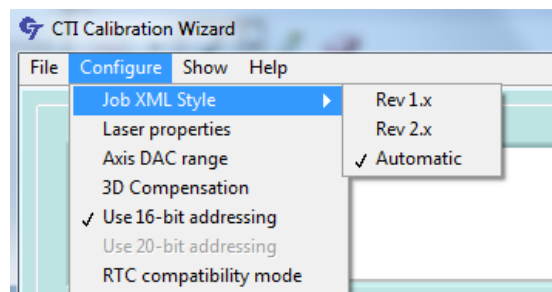
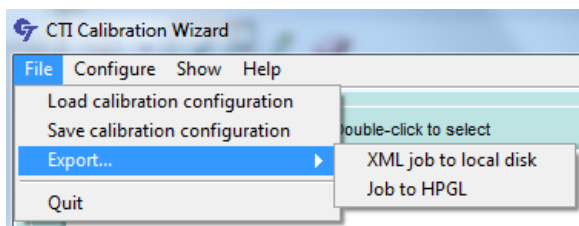
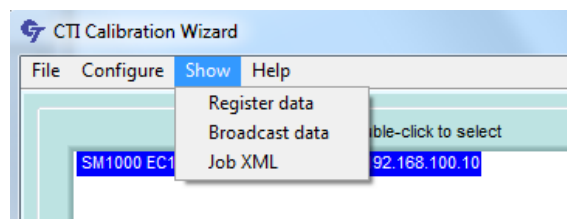
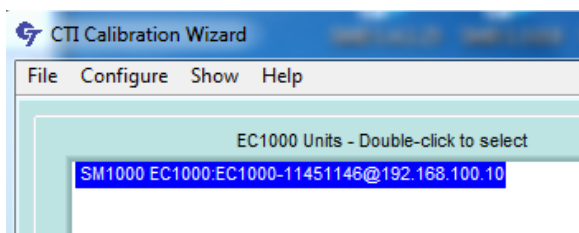
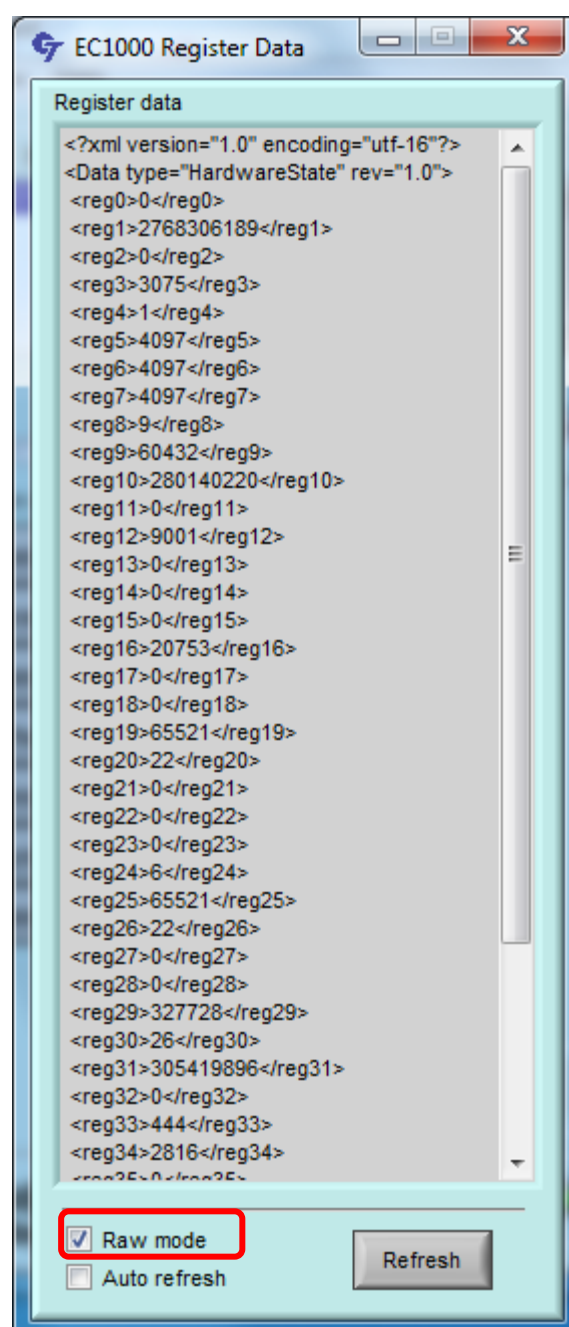
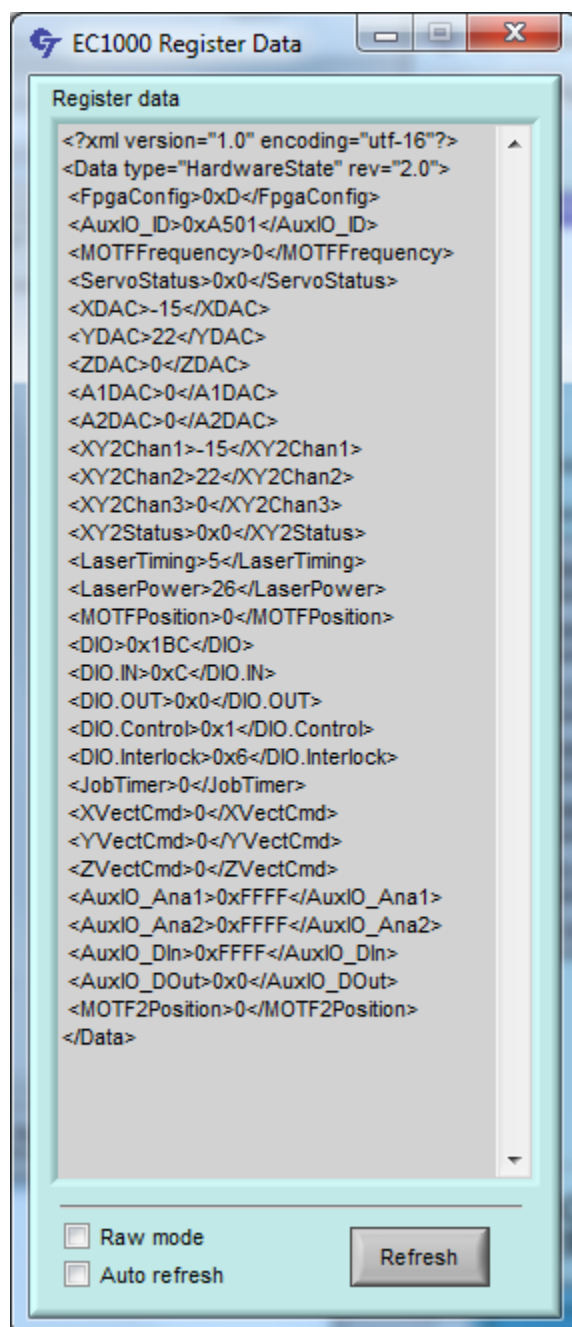


Figure 131: Combined Pincushion & "Barrel" Corrections Visualization

Appendix C: Calibration Wizard Menu Options





EC1000 Information

Module status		System information	
XPosAck	YPosAck	StreamVer	
XPos	YPos	MSN	EC1000-11451146
XActPos	YActPos	PVer	2.0.2
XTemp	YTemp	AVer	2.8.0.21980
ContrTemp		ObjExtVer	
XStatus	YStatus	FPGAfirmVer	280140220
YStatus		StateCode	1
XPower	YPower	LastError	0
Interlock		FreeTempStorage	7476
CurrentDIO		PermStoragePath	Disk
JobMarker		FreePermStorage	9235
JobDataCntr		FreeUSBStorage	0
		MAC	00:50:c2:4f:a5:a1
		NetMask	255.255.255.0
		NetAssign	1
		IP	192.168.100.10
		ConnectIP	192.168.100.1
		FriendlyName	SM1000 EC1000
		ConnectJob	
		Port	12200
		HSN	

EC1000 Broadcast Information

Exit

Marking Job

```

<Data type='JobData' rev='2.0'>
<Sequence>
<DeleteAllSegments> </DeleteAllSegments>
</Sequence>
</Data>
<Data type='JobData' rev='2.0'>
<Segment id='Preamble' deferred='True'>
<BeginJob> </BeginJob>
<set id='LaserModeConfig'>0x0</set>
<set id='GalvoDACConfig'>0x0</set>
<set id='ActiveCorrectionTable'>1</set>
<set id='XY2AddressMode'>0</set>
<set id='RTCCompatibility'>FALSE</set>
<set id='Units'>1</set>
<set id='XYCalFactor'>570.898600</set>
<set id='ZCalFactor'>500.000100</set>
<set id='VelocityComp'>0</set>
<set id='MarkSpeed'>10;11.417972</set>
<set id='JumpSpeed'>10;11.417972</set>
<set id='EnableLaser'>TRUE</set>
<set id='HeadParams'>0.000000; 0.000000</set>
<set id='FieldOffset'>0,0,0</set>
<set id='Transform'>1.0,0,0,0,0,1.0</set>
<set id='FieldOrientation'>0</set>
</Segment>
<Segment id='Params:Default' deferred='TRUE'>
<set id='LaserPower'>102</set>

```